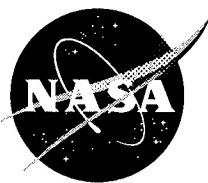


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Preliminary In-Flight Loads Analysis of In-Line Launch Vehicles Using the VLOADS 1.4 Program

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Space Administration

Marshall Space Flight Center

VLOADS 1.4 — Launch Vehicle Loads Analysis
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TECHNICAL MEMORANDUM

PRELIMINARY IN-FLIGHT LOADS ANALYSIS OF IN-LINE LAUNCH VEHICLES USING THE VLOADS 1.4 PROGRAM

1. INTRODUCTION

The vehicle loads (VLOADS) program calculates launch vehicle in-flight structural loads for preliminary design. The program may also be used to calculate structural loads for upper stages and planetary transfer vehicles. VLOADS is a Visual Basic for Applications (VBA) computer program which has been integrated into an easy-to-use Microsoft Excel user interface. The VLOADS program uses the individual Excel worksheets in its Excel workbook as input and output data files, in a manner that is very similar to the way that more traditional FORTRAN and BASIC programs have used text files as input and output files in the past. Launch vehicle information and input data such as aerodynamic coefficients, mass properties, propellants, engine thrusts, and performance data are compiled and analyzed by VLOADS to produce distributed shear loads, bending moments, axial forces, and vehicle line loads as a function of X-station along the vehicle's length. Translational accelerations and interface loads, if the launch vehicle has boosters or wings, are also computed.

VLOADS is a preliminary design tool that enables quick turnaround analysis of structural loads for launch vehicles, or other vehicles like upper stages and planetary transfer vehicles. VLOADS is as an alternative to the time-consuming and expensive chore of developing finite element models for detailed loads analysis. In preliminary design, much remains unknown about the detailed configuration to which the launch vehicle will mature and it becomes necessary to make some simplifying assumptions to initiate the process by which structural loads may be calculated for structural design and analysis. The VLOADS program operates in one vehicle plane at a time. This plane is generally assumed to be the pitch plane. The rotational acceleration and rotational velocity in this plane are assumed to be zero so that required unknowns, such as engine thrust in the pitch plane, can be determined. Out-of-plane forces and moments are ignored. However, a yaw plane loads set can be generated in the same manner as the pitch plane and the two loads sets combined. Vibrational effects are also not considered in the loads analysis.

The VLOADS program calculates the axial force, shear force, and bending moment distributions along the launch vehicle's length. It essentially treats the launch vehicle as a rigid beam. The Method of Sections is employed to determine the shear, moment, and axial load at any predetermined station number.

The assumptions concerning vehicle rotational accelerations of zero and rotational velocities of zero are necessary because these data cannot be solved for statically and an operating controls system design is required to produce such data from the flight trajectory. The necessary controls system design is generally not in place when preliminary loads analysis is needed.

VLOADS was developed as a Visual BASIC macro in a Microsoft Excel 5.0 workbook program on a Power Macintosh. VLOADS has also been implemented on a 486-class PC computer using Microsoft Excel 7.0a for Microsoft Windows 95. The standard distribution medium for VLOADS is a 3.5-in. (8.89-cm), 1.44MB diskette in MS-DOS format. Power Macintosh computers are capable of reading MS-DOS format diskettes; but if there are any problems, a Macintosh-formatted diskette can be made available. VLOADS was developed in 1996, and the current version was released to COSMIC, NASA's Software Technology Transfer Center, in 1997. The program is a copyrighted work with all copyright vested in NASA.

The VLOADS program may be purchased from COSMIC, University of Georgia, 382 East Broad Street, Athens, GA 30602-4272. COSMIC also has a site on the World Wide Web at <http://www.cosmic.uga.edu/>.

2. LOADS ANALYSIS METHODOLOGY IN VLOADS

VLOADS is a preliminary design tool that enables quick turnaround analysis of structural loads for launch vehicles, or other vehicles like upper stages and planetary transfer vehicles. VLOADS is an alternative to the time-consuming and expensive chore of developing finite element models for detailed loads analysis. In preliminary design, much remains unknown about the detailed configuration to which the launch vehicle will mature and it becomes necessary to make some simplifying assumptions to initiate the process by which structural loads may be calculated for preliminary structural design and analysis.

2.1 Assumptions

The VLOADS program operates in one vehicle plane at a time. This plane is generally assumed to be the pitch plane. The rotational acceleration and rotational velocity in this plane are assumed to be zero so that required unknowns, such as engine thrust in the pitch plane, can be determined. Out-of-plane forces and moments are ignored, and vibrational effects are also not considered in the loads analysis. The VLOADS program calculates the axial force, shear force, and bending moment distributions along the launch vehicle's length. It essentially treats the launch vehicle as a rigid beam. Figure 1 shows a free body diagram for a generic launch vehicle. Appendix A also includes a chart showing the free body diagram and the sum of force equations for the launch vehicle. Note that the X coordinate must increase positively from aft to nosecone.

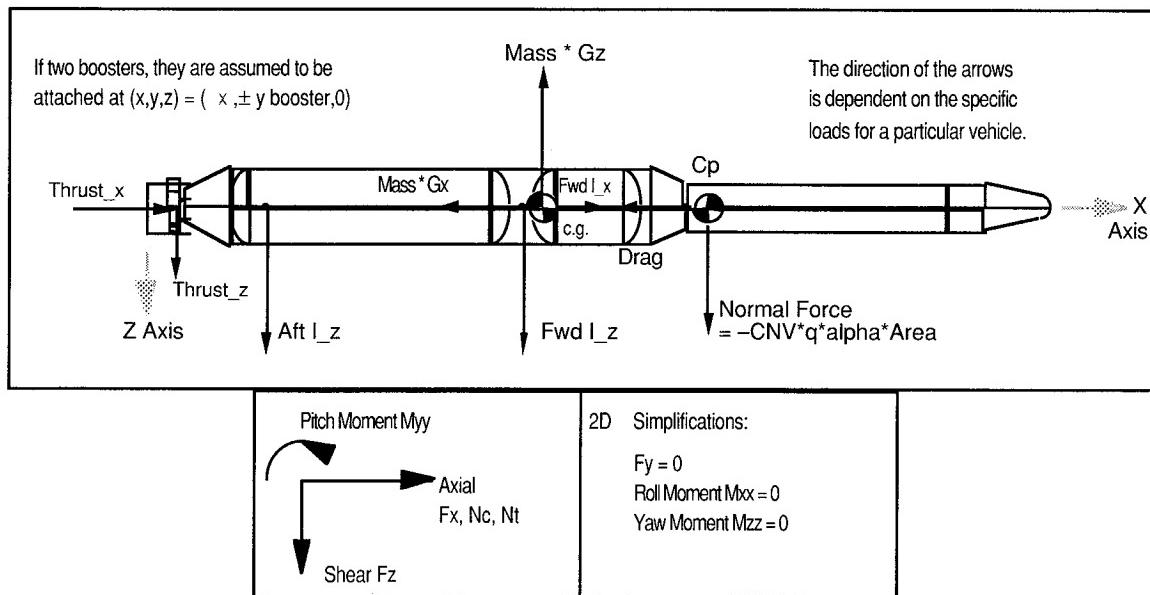


Figure 1. Free body diagram of a generic launch vehicle.

The Method of Sections is employed to determine the shear, moment, and axial loads at any predetermined station number. The rotational acceleration and rotational velocity in the pitch plane are set equal to zero, so that the sum of the pitch moment equals zero. This simplifies data entry because the user does not need to input moments of inertia with the vehicle's mass properties. Vibrational effects are also not considered in the loads analysis.

2.2 Method of Sections

The VLOADS program utilizes the Method of Sections to determine shear, moment, and axial forces at any point for which a "node" has been defined. A "node" is defined every time the user defines an X-station location in the "Mass.DAT" or "Aero.DAT" input sheets. Mass properties and/or aerodynamic coefficients do not have to be specified for every node, and the user may input a zero-mass or zero-coefficient value at any desired X-station to create a "node" of interest.

For shear and moment calculations, the loads analysis process begins at the aft-most node and works forward. Note that the VLOADS program assumes that launch vehicle X-stations increase positively as you move upward from the base of the vehicle to the nosecone. If your coordinate system is positive down instead of positive up, you will have to do a simple coordinate transformation to put your X-stations in the correct ascending order from aft to nose. The shear and moment are defined as zero at the aft-most point since the sum of all forces must be zero at the forward and aft ends of a vehicle in free flight. Axial load calculations begin at the forward end of the vehicle.

Figure 2 and its related equations illustrate the Method of Sections as used in the VLOADS program. The variable F_n is the sum of all applied forces acting in the Z direction at node n . Node $n+1$ is assumed to be an infinitesimally small distance forward of X-station n . Therefore, the forces acting at node $n+1$ are not taken into account until the next step—when node $n+1$ becomes node n . The process repeats itself until the last node is reached. Axial loads are calculated similarly, as shown in figure 3, where F_n is the sum of all applied forces acting in the X direction at node n .

2.3 Special Considerations for Launch Vehicles

A number of special considerations for launch vehicles have been incorporated into VLOADS.

2.3.1 Propellant Masses in Shear, Bending, and Axial Force Distributions

Propellant masses, for instance, must be handled differently for axial force calculations than for shear and bending moment calculations. In the VLOADS program, all propellant masses are input on the "Propellant.DAT" input sheet (app. B.4). For calculation of the shear and bending moment distributions, the VLOADS program will automatically distribute the propellant masses over " n " number of X-stations, as specified by the user in the "Propellant.DAT" sheet. For calculation of the axial force distribution, however, the propellant mass inertial forces which act in the X direction will only be reacted at a point which must represent the aft bulkhead tangency in that propellant tank. Only the aft bulkheads can react propellant inertial loads in the X direction, because the sidewalls of the propellant tanks do not support the fluid in the X direction. Aft bulkhead tangency points are input by the user in the "Propellant.DAT" input sheet, and the VLOADS program automatically handles redistribution of the propellant masses to these aft bulkhead tangency points for axial force distribution calculations during execution of the program.

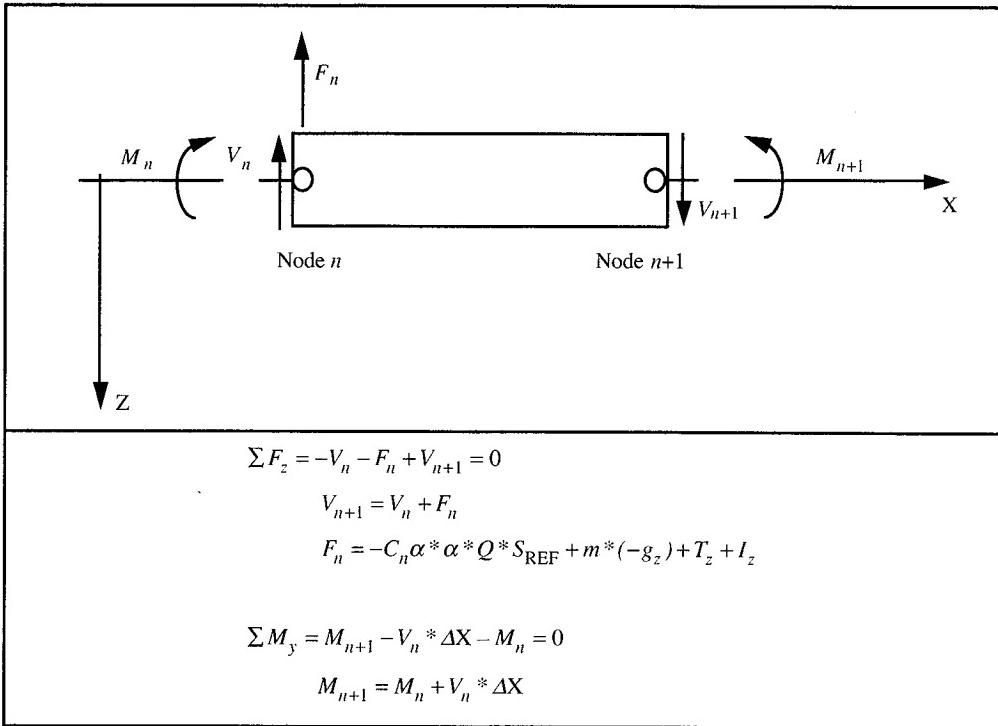


Figure 2. Method of Sections for shear and moment distribution calculations.

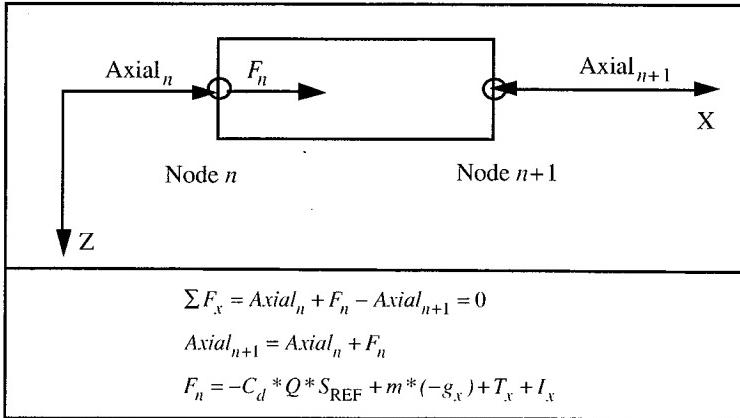


Figure 3. Method of Sections for axial force distribution calculations.

2.3.2 Line Loads

In addition to the shear, bending moment, and axial force distributions calculated by the program, VLOADS will also calculate tensile and compressive line loads for output to the “Loads.OUT” data sheet and the “Loads.PLOT” graph. Line loads are measures of load intensity which are derived from the stress equations for a monocoque shell with an applied axial force, pressure, and bending moment. Line loads, measured in pounds per inch, are calculated by dividing the longitudinal monocoque shell stress by a unit thickness. The equations for stress and line load in a thin-walled cylinder under axial loads are given in table 1.

Table 1. Stresses and line loads in a thin-walled cylinder.

Cylinder With Thin Walls
Cross-sectional (C.S.) area= $2 \pi R t$
Moment of inertia= $\pi R^2 t$
Fluid Enclosed in Cylinder
Enclosed fluid area= πR^2
Fluid axial force=Pressure* πR^2
Axial Force
σ_x axial=Axial force/C.S. area=Axial force/(2 $\pi R t$)
Line load N_x axial = σ_x axial/ t =Axial force/(2 πR)
Pressure, P
σ_x pressure=Fluid force/C.S. area= $P(\pi R^2)/(2 \pi R t) = (PR)/(2 t)$
Line load N_x pressure = σ_x pressure/ t =PR/2
Moment
σ_x moment=Moment/Inertia=Moment/($\pi R^2 t$)
Line load N_x moment = σ_x moment/ t =Moment/ (πR^2)

2.3.3 Pressure Relief of Compressive Buckling Loads

The axial force distribution for launch vehicles is, for the most part, compressive in nature. Compressive loads lead to buckling modes of structural failure. When determining the vehicle's line load distribution under compressive loads, the internal tank pressures must be taken into account because they have a load-relieving effect. The tank's internal gauge pressure is tensile and effectively reduces the axial longitudinal compressive load on the tank structure. Sometimes the pressure can provide enough relief to actually place the tank in tension. It is generally good engineering practice when determining ultimate compressive line loads to avoid multiplying load-relieving pressures or tensile loads by an engineering safety factor. The VLOADS program gives the user the option to handle relieving loads with or without safety factors. Section 5.5 contains more details.

2.3.4 Compressive/Tensile Bending Moments

In the axial load direction, bending moments act in compression on one side of the shell and in tension on the other side. This phenomena is apparent in the final ultimate compressive line load and ultimate tensile line load, equations (1) and (2), respectively. Moment in these equations is the absolute value of the moment calculated in table 1. Compressive forces and line loads are negative in sign. Tensile forces and line loads are positive in sign.

$$N_c \text{Ultimate} = \frac{\text{AxialForce}}{2\pi R} S.F. + (\text{pressure}) \frac{R}{2} - \frac{\text{Moment}}{\pi R^2} S.F. \quad (1)$$

Look at these equations carefully. For this load case, the axial force is assumed compressive, the pressure load is assumed tensile, and the bending moment is both tensile and compressive.

$$N_t \text{Ultimate} = \frac{\text{AxialForce}}{2\pi R} + \left\{ (\text{pressure}) \frac{R}{2} + \frac{\text{Moment}}{\pi R^2} \right\} S.F. \quad (2)$$

3. GENERAL INFORMATION ABOUT THE VLOADS PROGRAM

The VLOADS program may be purchased from COSMIC, University of Georgia, 382 East Broad Street, Athens, GA 30602-4272. COSMIC also has a site on the World Wide Web at <http://www.cosmic.uga.edu/>.

The VLOADS program was developed as a Visual BASIC program in a Microsoft Excel workbook. The “VLOADS” Microsoft Excel workbook contains five input worksheets, five input dialogs, three output worksheets, and three modules which contain the 25 Visual BASIC macros and 3 Visual BASIC functions which comprise the VLOADS program.

The “Aero.DAT” input worksheet contains discrete normal force coefficients per degree alpha (angle-of-attack) and axial force coefficients with their accompanying locations in terms of X–Station/Diameter (X/D) for the core vehicle only. This data is a product of aerodynamic analyses and will change from one vehicle to the next, and from one Mach number to the next.

The “Mass.DAT” input worksheet contains discrete masses which represent the vehicle structure, payload, avionics, engines, thermal insulation, power systems, and all other components. Propellant mass properties are a special case. If the propellant is in a tank that is nonintegral to the vehicle structure, such as a reaction control system or orbital maneuvering system tank, then that propellant mass should be input within “Mass.DAT.” However, if the propellant is in a tank that is integral to the vehicle structure, like the main liquid oxygen (lox) and liquid hydrogen (LH_2) propellant tanks in the space shuttle’s external tank (ET), then that propellant mass should be input in the “Propellant.DAT” input worksheet. The “Mass.DAT” sheet is also where the user may enter some zero-mass X-stations for other locations on the vehicle where a loads output is desired, such as field splices and joints.

The “Propellant.DAT” input worksheet contains the propellant masses and pressures for all tanks that are integral to the vehicle’s structure. Please read the paragraph above for more information on integral versus nonintegral tankage.

The “Data.SORT” output worksheet contains the raw input data after it has been compiled and sorted. It is useful for debugging should problems occur during program execution.

The “Loads.OUT” output worksheet contains the calculated load distributions. It is a sorted listing of vehicle X-stations and their corresponding shear, bending moment, axial load, and line load distributions.

The “Loads.PLOT” output worksheet contains a plot of the line load distributions versus X-station. This plot is automatically updated every time that VLOADS is run. If the user desires to create plots of the other load distributions, it is a simple matter to insert a new worksheet or chart on which a new plot may be created. The Microsoft Excel user’s manuals and on-line help features can tell you how to create graphs and plots. Note, however, that any new plots that the user should choose to create will NOT automatically update each time that VLOADS is run. They must be manually updated for each new run.

Other worksheets are hidden from the user, but may be accessed by using the “Format/Sheet/Unhide...” command within Microsoft Excel (this feature was supported in Excel 5.0 for the Macintosh and Excel 7.0 for Windows 95). The default data sheet (the data that is input via the dialog sheets when VLOADS is run), the dialog sheets, and the Visual BASIC coding are all hidden from view for more efficient operation and to provide a less cluttered work environment.

When the user clicks on the “RUN “VLOADS”” button on the “START” worksheet (app. B.1), the VLOADS program will be executed and the user will have the opportunity to edit the vehicle properties not contained in the “Aero.DAT,” “Mass.DAT,” or “Propellant.DAT” input worksheets through a series of dialog windows that will be displayed. The dialog windows are entitled:

- Program Control for the “VLOADS” Visual BASIC Program
- Edit Aerodynamic & Performance Parameters
- Edit Mass Parameters
- Edit Vehicle Geometry
- Edit Safety Factors.

VLOADS was developed as a Microsoft Excel 5.0 workbook program on a Power Macintosh computer. It has also been tested and implemented on a 486-class PC computer using Microsoft Excel 7.0 for Microsoft Windows 95. VLOADS was developed in 1996, and the current version was released to COSMIC, NASA’s Software Technology Transfer Center, in 1997. The program is a copyrighted work with all copyright vested in NASA.

4. EXAMPLE PROBLEM

The following example problem will be used to illustrate operation of the VLOADS program. The vehicle under investigation is shown below. It consists of a 27.6-ft-diameter core stage derived from the space shuttle's ET with two redesigned solid rocket motors (RSRM's) as boosters. The payload shroud diameter is 36 ft. The launch vehicle is illustrated in figure 4.

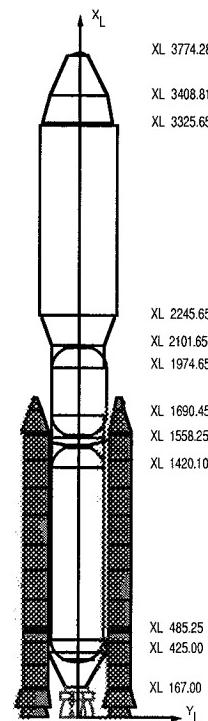


Figure 4. Example problem vehicle.

The structural loads are to be evaluated at the point of maximum dynamic pressure (Max Q). All VLOADS data files and windows for this example problem will be shown in sections 4–6 and appendices B–C.

Table 2 is a copy of the aerodynamic normal force coefficient input data, and table 3 represents the axial force coefficient data. The reference diameter for this data is 331 in. and the reference area is 607 ft².

The two sets of aerodynamic properties should be combined and input into one file, the "Aero.DAT" input file. The completed "Aero.DAT" file can be found in appendix B.2. This data need not be sorted into ascending order for entry into the "Aero.DAT" file.

Table 2. Coefficients for normal force aerodynamic data (ref. area=607 ft²).

X/D_ref (unitless)	C _n a per degree
10.733	0.03380
10.145	0.02410
9.596	0.02160
8.860	0.01070
8.074	0.00440
7.309	0.00370
6.388	-0.00790
5.943	-0.01090
5.447	-0.00180
4.125	0.00480
1.693	0.01740
Core C _n =	0.09990
Booster C _n =	0.07560
TOTAL C _n =	0.17550
D_ref=331 in.	

Table 3. Coefficients for axial force aerodynamic data (ref. area=607 ft²).

X/D_ref (unitless)	Axial Aero (C _d)
11.3220	0.09670
11.2977	0.20250
10.6212	0.19540
10.1523	0.03030
6.8894	0.04310
6.4147	0.12330
Core C _d =	0.69130
Booster C _d =	0.33600
TOTAL C _d =	1.02730
D_ref=331 in.	

With the aerodynamic data entered into the “Aero.DAT” file, we turn our attention to the launch vehicle mass properties. The distributed mass properties of the core vehicle at Max Q is shown in table 4.

Only the core mass properties in table 4 should be entered on the VLOADS “Mass.DAT” input worksheet (app. B.3). Booster masses and propellant masses are not input through “Mass.DAT.” Instead, booster masses will be input in a mass properties dialog (section 5.2) that you execute by clicking on a button when running the VLOADS program. The propellant masses will be entered in a “Propellant.DAT” input sheet (app. B.4), which is similar to the propellant mass breakdown shown in table 5.

To improve accuracy of the structural load calculations, masses which occupy a relatively large volume, such as the lox, LH₂, or payload, should be broken up into smaller masses distributed over several X-station locations. The more detailed the mass breakdown, the more accurate the results. Ideally, all the masses in the “Mass.DAT” file will be of the same order of magnitude. However, breaking some of the large masses into many smaller ones may be more trouble than its worth, depending on the maturity of the launch vehicle’s design (preliminary design, detailed design, production, etc.) and the level of fidelity that you desire in your analysis. One nice feature in VLOADS is that it will automatically distribute the propellant masses from a starting X-station to an ending X-station, depending on the number of divisions that you specify in the “Propellant.DAT” input sheet.

The user is now ready to update the default settings and parameters in VLOADS, and to run the program to calculate structural loads.

Table 4. Mass properties for example problem.

Description	Weight (lb)	X c.g. (ft)
<u>Core</u>		
Shroud Nose	3,300	280.50
Shroud Door +Y	9,350	228.00
Shroud Door -Y	9,350	228.00
Strongback	28,000	219.00
Payload Adapter/ASE	10,600	182.00
Kickstage (Wet)	17,178	178.00
Payload +Y	58,110	219.00
Payload -Y	58,110	219.00
Transition Str.	7,090	176.00
Fwd ET Str.	3,832	167.00
Lox Tank & Subsystem	18,742	152.00
Intertank	16,162	129.00
LH ₂ Tank & Subsystem	36,452	76.00
Aft & Thrust Str	16,701	27.00
Three SSME's	20,887	8.00
Prop. Subsys. & Avion.	17,207	21.00
gox and Residuals	2,966	152.00
GH ₂ and Residuals	1,238	76.00
Aft Residuals	5,557	21.00
Subtotal =	340,832	155.48
<u>Propellants</u>		
Wp lox (Max Q)	1,274,764	148.00
Wp LH ₂ (Max Q)	212,461	69.00
Subtotal =	1,487,225	136.71
<u>Boosters</u>		
RSRB +Y (Max Q)	667,908	64.20
RSRB -Y (Max Q)	667,908	64.20
Subtotal =	1,335,816	64.20
TOTAL =	3,163,873	108.12

Table 5. Main propellant data for example problem.

Propellant Name	Ullage Pressure (psig)	Pressure From X-Station (in.)	Pressure To X-Station (in.)	Propellant Mass (lbm)	Mass From X-Station (in.)	Mass To X-Station (in.)	No. of X-Stations to Distribute Mass Over
Wp lox (Max Q)	20	1,690.45	1,974.65	1,274,764	1,558.25	2,101.65	5
Wp LH ₂ (Max Q)	32	425.00	1,420.10	212,461	425.00	1,420.10	7

5. RUNNING THE VLOADS PROGRAM

The most efficient way for the user to become familiar with the VLOADS program and the methodology with which it calculates loads is to determine the structural loading for a sample launch vehicle, such as the example vehicle described in section 4.

Before we can begin running VLOADS, we must make sure that a consistent coordinate system will be used for data input. It is essential that the user maintain close vigilance over coordinate system identification since they will receive data from several sources. The VLOADS program requires that the X coordinate be in the direction of flight with the origin somewhere aft of the aft-most data point at the bottom of the vehicle. Negative station numbers are not allowed. An origin of X=0 at the engine exit plane is commonly used. Figure 5 shows the reference configuration of the core vehicle free body diagram in the newly defined loads coordinate system.

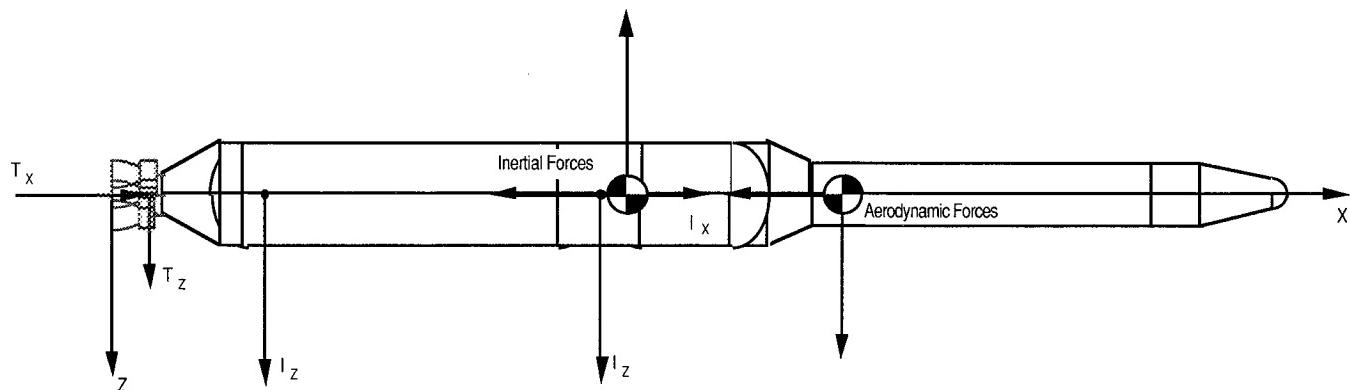


Figure 5. Reference configuration of the core vehicle free body diagram.

After the coordinate system is established, the user should begin by inputting aerodynamic and mass properties data in the “Aero.DAT” and “Mass.DAT” sheets. The data in these sheets is organized in columns. ***Do not skip rows when inputting your data*** because VLOADS assumes that the first empty row that it encounters marks the end of the data file. The VLOADS program reads the first four columns of data in the “Aero.DAT” sheet down to the first blank row and reads the first three columns of data in the “Mass.DAT” sheet down to the first blank row.

5.1 Inputting Aerodynamic Properties and Performance

Aerodynamic properties are input and stored on the “Aero.DAT” worksheet. To view the “Aero.DAT” input worksheet, you can (1) click the “Input Aero Data & Edit Performance” button on the “START” worksheet (app. B.1) within the “VLOADS” workbook or (2) click on the “Aero.DAT” tab that appears at the bottom of the “VLOADS” Excel workbook (this feature was supported in Excel 5.0).

for the Macintosh and Excel 7.0 for Windows 95). Appendix B.2 includes a copy of the “Aero.DAT” input worksheet that was created from the aerodynamic data provided for the example vehicle in section 4.

Please note that the VLOADS program will run without aerodynamic loads, if the user should choose to leave the “Aero.DAT” input worksheet blank due to insufficient data, or in case he is modeling an upper stage or planetary transfer vehicle that does not experience atmospheric loads. It is highly recommended that aerodynamic data be included for atmospheric vehicles because it is a significant contributor to the launch vehicle’s structural loads.

The “Aero.DAT” file contains discrete normal coefficients per degree alpha (angle of attack) and drag coefficients with their accompanying locations in terms of X/D for the core vehicle. Aerodynamicists like to output aerodynamic forces in terms of X/D (X-station over a reference diameter) because aerodynamic data in this format will be valid for the launch vehicle even if it has to be photographically resized to a smaller or larger shape during design. The reference diameter, which the user is prompted for in the “Edit Aerodynamic & Performance PARAMETERS” window, is used to convert X/D locations to X-stations within the VLOADS Program.

Distributed aerodynamic coefficients only need to be input for the core of the launch vehicle because VLOADS only calculates loads distributions for the core launch vehicle. Boosters are treated as separate entities and the user will be prompted for summary booster information such as weight, thrust, and total normal force coefficient when they click on the “Edit Aerodynamic & Performance PARAMETERS” button on the “Aero.DAT” worksheet.

After the aerodynamic C_na and C_d data versus X-station is input, the user should then click on the “Edit Aerodynamic & Performance PARAMETERS” button on the “Aero.DAT” worksheet. A dialog box will pop up in a new window, and it will prompt the user for input. The “Edit Aerodynamic and Performance PARAMETERS” window is shown in figure 6.

The units of measurement to which the data must conform are listed with each item. If no units are given, the item is dimensionless. The “Total Booster Normal Force Coefficient” refers to the sum of all booster coefficients. This may require additional input from the aerodynamicist since leeward boosters may be blanked from the flow and thus experience a reduction in normal force coefficient. The other entries are self-explanatory. The user may use the mouse or “TAB” key to move from edit field to edit field. When the user is satisfied with the data entries, click “Continue” to return to the “Aero.DAT” sheet.

If the sum of the core normal force coefficients contained in the “Aero.DAT” file plus the booster normal force coefficient input in the dialog box does not equal the total vehicle normal force coefficient, which is also input in the dialog box as a checksum, within 0.1 percent, an error message will appear when VLOADS is run.

Edit Aerodynamic & Performance PARAMETERS

AERODYNAMIC PARAMETERS:	
The DETAILED Aerodynamic PROPERTIES (C_n & C_d versus X-station) are located on the "Aero.DAT" sheet.	
Total Launch Vehicle (Integrated Stack)	
Stack Normal Force Coeff. (checksum)	0.1756
Stack Center of Pressure (in)	2117.97
Stack Drag Coefficient	1.0273
<u>Boosters (if the vehicle has them)</u>	
Total Booster Normal Force Coefficient	0.0756
<u>Core of the Launch Vehicle</u>	
Aerodynamic Reference Area (sq. ft.)	607
Aero Reference Diameter (in)	331
PERFORMANCE PARAMETERS:	
Dynamic Pressure (psf)	717
Angle of Attack (°)	6
Total Thrust of Stack (lbs)	6,242,275
Core Vehicle Thrust (lbs)	1,676,499

Continue

Figure 6. “Edit Aerodynamic & Performance PARAMETERS” dialog box.

5.1.1 “No Booster” Case

If the user’s launch vehicle does not have boosters, the user should input a zero value in the “Total Booster Normal Force Coefficient” input box. The user should also input a zero value for the “Total Mass of Boosters” input that appears in the “Edit Mass PARAMETERS” dialog, shown later in figure 7. VLOADS will then run a “No Booster” case to determine launch vehicle loads.

5.1.2 “Winged Vehicle” or “Zero Thrust Attachments” Case

If the user would like to model a launch vehicle with wings, it is possible to treat the wings as zero-thrust boosters. For a winged vehicle, the user should make the total thrust of the stack equal to the core vehicle thrust in the “Edit Aerodynamic & Performance PARAMETERS” dialog. In figure 6, if we

were to model wings that had the same aerodynamic and mass properties as our boosters, we would input 1,674,499 lb for both “Total Thrust of Stack” and “Core Vehicle Thrust.”

After all of the aerodynamic data and performance parameters are input in the “Aero.DAT” worksheet and “Edit Aerodynamic & Performance PARAMETERS” dialog, the user should return to the “START” worksheet by (1) clicking the “Go to START Sheet” button or (2) clicking on the “START” tab that appears at the bottom of the “VLOADS” Excel workbook (this feature was supported in Excel 5.0 for the Macintosh and Excel 7.0 for Windows 95).

5.2 Inputting Mass Properties

Mass properties are input and stored on the “Mass.DAT” worksheet. To view the “Mass.DAT” worksheet, you can (1) click the “Input Mass Properties” button on the “START” worksheet (app. B.1) within the “VLOADS” workbook or (2) click on the “Mass.DAT” tab that appears at the bottom of the “VLOADS” Excel workbook (this feature was supported in Excel 5.0 for the Macintosh and Excel 7.0 for Windows 95). Appendix B.3 includes a copy of the “Mass.DAT” worksheet that was created from the mass properties data provided for the example vehicle in section 4.

The “Mass.DAT” sheet contains discrete masses which represent the core vehicle structure, payload, avionics, electronics, thermal protection system, and any other points of interest not already defined. Edit the “Mass.DAT” sheet in the same manner as the “Aero.DAT” sheet. Comments may be added to clarify your input data in the fourth column. Do not input mass properties for the boosters or for any of the main propellants that are in tanks which are load-bearing and integral with the vehicle’s outside skin. Reaction Control System (RCS) propellants, Orbital Maneuvering System (OMS) propellants, and any other propellants in tanks which are nonintegral to the vehicle’s outside skin should still be input in the “Mass.DAT” sheet. Booster mass properties will be input in the “Edit Mass PARAMETERS” dialog and main propellant mass properties will be input in the “Propellant.DAT” input sheet.

The user may also add reference X-stations to the mass properties input by entering zero for the mass of any X-station numbers of interest which do not have an associated lumped mass. The user should include reference X-station locations with a mass of zero for the following points of interest:

- Aft propellant tank dome tangencies
- Forward propellant tank dome tangencies
- Aft booster attach point, if any
- Forward booster attach point, if any
- Engine gimbal point
- Any other point of interest.

In addition, your output data will be clearer and more accurate if additional station numbers and zero masses are inserted just before (-1 in.) and just after (+1 in.) all major points of interest. *We highly recommend that you adhere to this practice.* Please refer to the example “Mass.DAT” sheet in appendix B.3 to see one example of how this can be done.

After mass properties versus X-station are input, the user should click the “Edit Mass PARAMETERS” button on the “Mass.DAT” worksheet. A dialog box will pop up in a new window, and it will prompt the user for input. The “Edit Mass PARAMETERS” window is shown in figure 7.

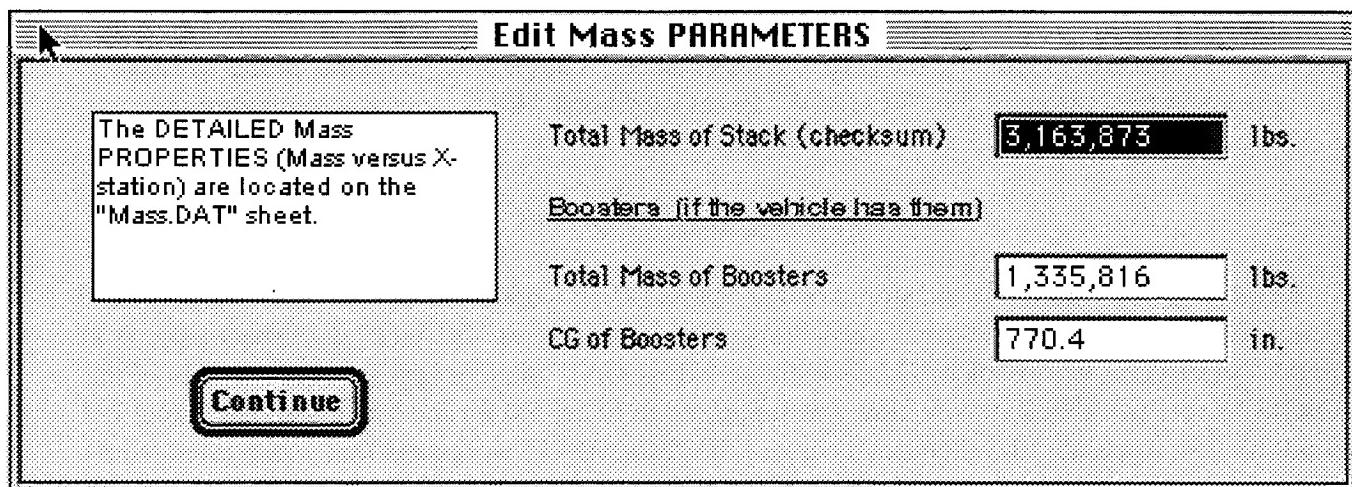


Figure 7. “Edit Mass PARAMETERS” dialog box.

5.2.1 “No Booster” Case

If the user’s launch vehicle does not have boosters, the user should input a zero value in the “Total Mass of Boosters” input box. VLOADS will then run a “No Booster” case to determine launch vehicle loads.

If the sum of the core vehicle masses in the “Mass.DAT” file and the booster mass entered in the “Edit Mass Properties” window does not equal the total vehicle stack mass that was input in the window as a checksum within 0.1 percent, an error message will occur. The message will display the total core vehicle weight (i.e., the sum of all masses in the “Mass.DAT” file), the recorded booster weight, and the recorded total vehicle weight. The program will then prompt the user for corrective measures.

After all of the mass properties and parameters are input in the “Mass.DAT” worksheet and “Edit Mass PARAMETERS” dialog, the user should return to the “START” worksheet by (1) clicking the “Go to START Sheet” button or (2) clicking on the “START” tab that appears at the bottom of the “VLOADS” Excel workbook (this feature was supported in Excel 5.0 for the Macintosh and Excel 7.0 for Windows 95).

5.3 Inputting Main Propellant Masses and Pressures

Propellant masses and pressures for integral, load-bearing tankage are input and stored on the “Propellant.DAT” worksheet. To view the “Propellant.DAT” input worksheet, you can (1) click the “Input Ascent Propellants” button on the “START” worksheet (app. B.1) within the “VLOADS” workbook or (2) click on the “Propellant.DAT” tab that appears at the bottom of the “VLOADS” Excel workbook (this feature was supported in Excel 5.0 for the Macintosh and Excel 7.0 for Windows 95).

Appendix B.4 includes a copy of the “Propellant.DAT” input worksheet that was created from the propellant data provided for the example vehicle in section 4.

Propellant masses must be handled differently for axial force calculations than they are for shear and bending moment calculations. For calculation of the shear and bending moment distributions, the VLOADS program will automatically distribute the propellant masses over “*n*” number of X-stations, as specified by the user in the “Propellant.DAT” sheet. The discrete masses of propellant that are distributed through the tank may be thought of as slices or, more accurately, discs of propellant. After calculating the shear and bending moment distributions with the distributed propellant mass, VLOADS will make another automatic adjustment. For calculation of the axial force distribution, the propellant mass inertial forces which act in the X direction will only be reacted at a point which must represent the aft bulkhead tangency in that propellant tank. Only the aft bulkheads can react propellant inertial loads in the X direction because the sidewalls of the propellant tanks do not support the fluid in the X direction. Aft bulkhead tangency points are input by the user in the “Propellant.DAT” input sheet, and the VLOADS program automatically handles redistribution of the propellant to these aft bulkhead tangency points for axial force distribution calculations during execution of the program.

After all of the propellant masses and pressures from integral, load-bearing tankage are input in the “Propellant.DAT” worksheet, the user should return to the “START” worksheet by (1) clicking the “Go to START Sheet” button or (2) clicking on the “START” tab that appears at the bottom of the “VLOADS” Excel workbook (this feature was supported in Excel 5.0 for the Macintosh and Excel 7.0 for Windows 95).

5.4 Inputting Vehicle Geometry

To input vehicle geometry such as launch vehicle radii versus X-station, forward and aft booster attachment points, and the engine gimbal point (usually considered to be the point of thrust application), the user should click on the “Edit Geometric Parameters” button on the “START” worksheet (app. B.1). A dialog box will pop up in a new window, and it will prompt the user for input. The “Edit Vehicle Geometry” window is shown in figure 8.

The booster thrust loads are assumed to act at the same X-station as the core vehicle thrust. The forward attach point is assumed to carry X, Y, and Z direction loads, while the aft attach is assumed to transmit Y and Z direction loads only. Recall that the VLOADS program is a two-dimensional tool so that only information in the X-Z plane is input or output. If a vehicle aft booster attach is used to carry X, Y, and Z loads and the forward attach used to carry Y and Z loads then simply input the X-station for the aft interface in the “Fwd Booster Attach Location” edit field, and vice versa.

The user may also identify up to 10 changes in radius along the vehicle. If you should choose to input fewer than 10 radii points, you may duplicate some of your data points to complete the field of 10. The radii that you enter are only used in the calculation of the tensile and compressive line load distributions. They are not used in any other calculation. When calculating line loads, the VLOADS program will use a simple linear interpolation of the radii data to determine what radius to use at a particular X-station location.

Edit Vehicle Geometry

<p>Identify Up to 10 Radii Breaks</p> <p>More Launch Vehicle X-station data is listed on both the "Aero.DAT" and "Mass.DAT" worksheets.</p> <p>Boosters (if boosters are attached)</p> <p>Fwd Booster Attach Location (in) <input type="text" value="1,558.25"/></p> <p>Aft Booster Attach Location (in) <input type="text" value="485.25"/></p> <p>Propulsion</p> <p>Point of Thrust Application (in) <input type="text" value="167.00"/></p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%;">X-station</th> <th style="width: 50%;">Radius (in)</th> </tr> </thead> <tbody> <tr><td>0.00</td><td>128.00</td></tr> <tr><td>167.00</td><td>128.00</td></tr> <tr><td>425.00</td><td>331.20</td></tr> <tr><td>1,420.10</td><td>331.20</td></tr> <tr><td>1,690.45</td><td>331.20</td></tr> <tr><td>1,974.65</td><td>331.20</td></tr> <tr><td>2,101.65</td><td>331.20</td></tr> <tr><td>2,245.65</td><td>432.00</td></tr> <tr><td>3,325.65</td><td>432.00</td></tr> <tr><td>3,774.28</td><td>20.00</td></tr> </tbody> </table>	X-station	Radius (in)	0.00	128.00	167.00	128.00	425.00	331.20	1,420.10	331.20	1,690.45	331.20	1,974.65	331.20	2,101.65	331.20	2,245.65	432.00	3,325.65	432.00	3,774.28	20.00
X-station	Radius (in)																						
0.00	128.00																						
167.00	128.00																						
425.00	331.20																						
1,420.10	331.20																						
1,690.45	331.20																						
1,974.65	331.20																						
2,101.65	331.20																						
2,245.65	432.00																						
3,325.65	432.00																						
3,774.28	20.00																						

Continue

Figure 8. “Edit Vehicle Geometry” dialog box.

5.5 Inputting Safety Factors

To input safety factors and uncertainty factors, the user should click on the “Edit Safety Factors” button on the “START” worksheet (app. B.1). A dialog box will pop up in a new window, and it will prompt the user for input. The “Edit Safety Factors” window is shown in figure 9.

Edit fields are provided for inputting multiplication factors to increase the bending moment and axial loads to account for uncertainty in the load environment. These increases are reflected in the bending moment and axial loads, as well as the line loads. An uncertainty factor of 1.3 or more for the bending moment is generally accepted to account for dynamic pressure excursions, angle-of-attack exceedances, vehicle aeroelastic effects, etc. If performance modeling of the vehicle trajectory indicates that all or most of this 30 percent will be “eaten up” by dynamic pressure and angle-of-attack excursions alone, the factor should be increased accordingly. Engineering judgment and historical precedent are the rule here. For axial loads, an uncertainty factor of 1.05 to 1.15 is usually sufficient. Axial load multiplication factors are applied to the vehicle axial loads to account for dynamic pressure excursions, engine thrust above 100 percent, dynamic effects, etc. Large instantaneous changes in vehicle mass, such as booster separation, may warrant a higher multiplication factor.

The safety factor is only used in the calculation of the compressive and tensile line loads. All other loads in the “Loads.OUT” sheet are output as limit loads that are not multiplied by a safety factor.

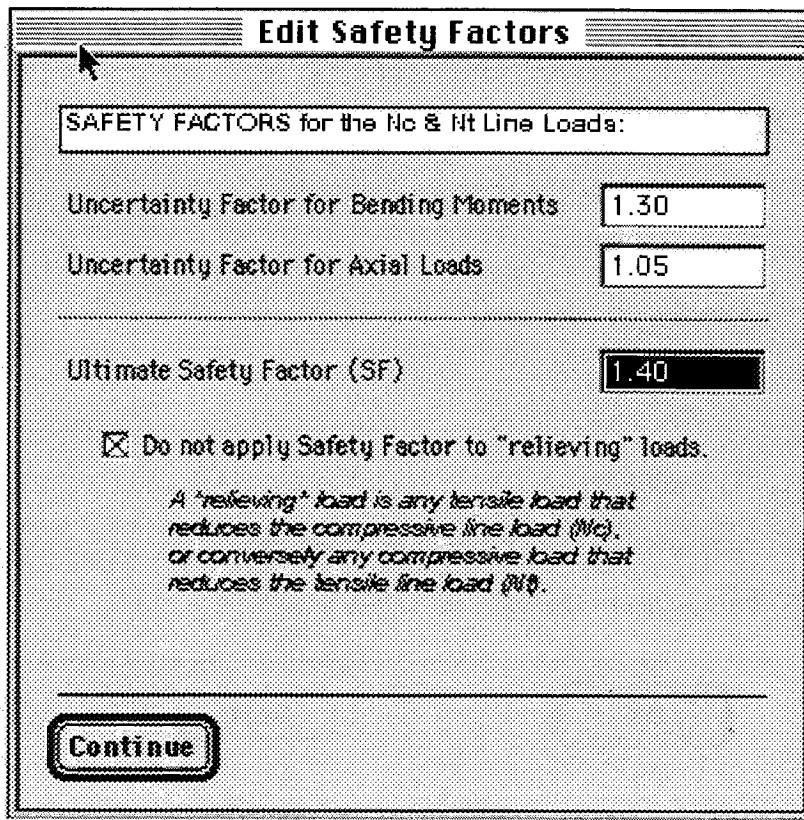


Figure 9. “Edit Safety Factors” dialog box.

The axial force distribution of a launch vehicle is, for the most part, compressive in nature. Compressive loads lead to buckling modes of structural failure. When determining the vehicle’s line load distribution under compressive loads, tensile loads like internal tank pressures or positive bending moments must be taken into account because they have a load-relieving effect. Consider tank gauge pressure. Normally, the tank’s internal gauge pressure is tensile and effectively reduces the axial compressive load on the tank structure. Sometimes, the pressure can provide enough relief to actually place the tank in tension. However, since the pressure is a relieving load, it is generally good engineering practice when determining ultimate compressive line loads to avoid multiplying pressures by an engineering safety factor. The VLOADS program gives the user the option to handle pressure-relieving loads with or without safety factors by clicking on the check box in the “Edit Safety Factors” dialog (fig. 9).

5.6 Starting VLOADS Program Execution

After the user inputs all of the vehicle’s data in the input worksheets and dialog boxes, it is time to run the VLOADS program. To run VLOADS, click on the “RUN “VLOADS”” button on the “START” worksheet (app. B.1). The first dialog box to appear will be the “Program Control for the “VLOADS” Visual BASIC Program” window, as shown in figure 10.

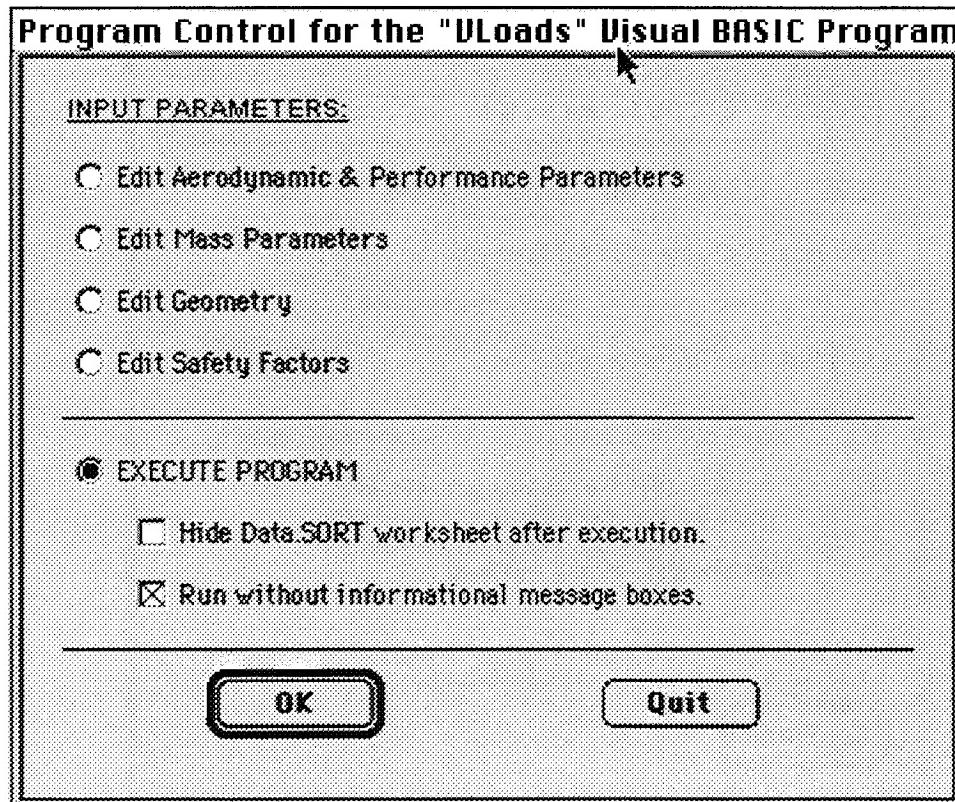


Figure 10. "Program Control for the "VLOADS" Visual BASIC Program" dialog box.

The "Program Control" window allows the user to execute the VLOADS Visual BASIC code. The user may also navigate through the edit windows again to check or edit the input parameters. To edit a set of properties, simply select that line item and click "OK." The user will be returned to the "Program Control" window after editing each of the data sets listed.

The "Program Control" window also includes check boxes for "Hide Data.SORT worksheet after execution" and for "Run without informational message boxes." Running with messages will cause a message box to appear on the screen when certain key data points are encountered by the program, such as the gimbal point and the forward and aft booster attach points. If these points are not encountered, the shear, moment, or axial load curves will not close. It is advisable to run with messages turned on for the first run to assist in verifying that all necessary inputs have been entered.

To run VLOADS, the user should select "Execute Program," and click "OK." This will run the portion of the Visual BASIC code which actually calculates the vehicle's structural load distributions.

6. ANALYSIS RESULTS

When VLOADS finishes calculating structural loads and completes its run, the output data will be stored in three worksheets. The “Data.SORT” worksheet will contain a sorted data deck of the “Aero.DAT,” “Mass.DAT,” and “Propellant.DAT” sheets. The “Loads.OUT” worksheet will contain a table of the calculated vehicle loads, and the “Loads.PLOT” sheet will contain a plot of the structural line loads versus X-station.

6.1 The “Data.SORT” Sheet

The “Data.SORT” sheet for the example problem is shown in appendix C.1. The VLOADS program combines the raw, unsorted data from the “Aero.DAT,” “Mass.DAT,” and “Propellant.DAT” input worksheets into one data set, sorts it, and then writes the sorted data to the “Data.SORT” worksheet. This data is then reread to form the overall data set for loads analysis. Loads will be generated for each data point in the “Data.SORT” sheet.

The “Data.SORT” worksheet also contains the results of some internal calculations, such as the core vehicle center of gravity; the center of pressure, the total aerodynamic forces in pounds; booster interface loads, if any, and the calculated vehicle accelerations. The “Data.SORT” worksheet is useful for debugging if a problem is experienced.

To verify that the loads model was set up correctly, and to check for discrepancies, the center of gravity should be checked by hand or compared to the mass properties statement. Also, the total mass should be verified against the mass properties statement, and the axial and lateral accelerations should be verified against the performance data. The totals of the aerodynamic properties should be verified by comparison with the table of aerodynamic properties generally provided by the aerodynamicist. Booster interface forces, if any, may be checked by hand through a simple free body diagram and summation of forces and moments. The interface forces represent the total interface loads for all of the boosters together. Any further detailed analysis of interface loads, as might result from a booster being partially blanked by the core, must be done by hand.

6.2 The “Loads.OUT” File

The “Loads.OUT” sheet for the example problem is shown in appendix C.2. It contains a series of column headings and the tabulated vehicle loads. *The most important item to verify is that the shear, bending moment, and axial load distributions have all “closed,” meaning that their values must be zero at both ends of the vehicle.* The curves must close for a vehicle in free flight. If the values are relatively small (i.e., <10), they can be assumed to be zero. The most likely cause for nonclosing curves is that a key X-station, such as the fuel tank bulkhead tangencies; booster interface locations; or engine gimbal point, was not entered into the “Mass.DAT” sheet and was therefore not encountered during program execution.

After inspecting the “Loads.OUT” sheet, the structural loads data versus X-station can be copied, pasted, and plotted in CricketGraph, Microsoft Excel, or another graphing program. When plotting, check the shear curve to see if any large load changes occurred in the proper locations. Engine thrust and interface loads produce large changes in the shear curve. The axial load curve may also be plotted and inspected in the same manner. Large concentrated masses (e.g., main propellant masses like lox and LH₂), in-line propellant tank pressures, interface loads, and engine thrust loads all cause abrupt changes in the axial load curve. It would be wise for the user to familiarize themselves with the generation of shear and bending moment diagrams as described in any introductory structures or mechanics of materials text. The rules governing the shear and moment diagrams of beams apply here.

It is often very useful to speak of structural loads in terms of line loads. A line load is a measure of load intensity determined as if the moment, pressure, and axial load were all acting on a monocoque cylinder of radius R . Abrupt changes in the line load curves are caused by abrupt changes in the moment and axial loads, as well as internal pressure changes (psig). The line load is valuable in comparing load cases to determine structural load drivers and for assessing vehicle capability. Section 2.3 discusses line loads in more detail.

6.3 The “Loads.PLOT” File

The VLOADS program automatically plots the compressive and tensile line loads for the vehicle on the “Loads.PLOT” worksheet. The “Loads.PLOT” chart for the example problem is shown in figure 11 and again in appendix C.3.

In figure 11, positive values for line load indicate tension while negative values indicate compression. It is apparent from the plot that the line loads close, converge to zero, at the aft end of the vehicle ($X=96$ in.) and at the forward end of the vehicle ($X=3,774.28$ in.). Remember that the loads must close to zero at both ends of a vehicle in free flight. The abrupt changes, or “spikes,” in the line load curves are due to concentrated masses (the lox and LH₂ propellant masses), propellant tank pressures (LH₂ from $X=425$ to $X=1,420.10$ in., and lox from $X=1,690.45$ to $X=1,974.65$ in.), interface loads, and the engine thrust loads.

Figure 11 shows the Max Q line loads for our example vehicle. Other ascent load sets that could have been run and plotted include liftoff, booster separation, main engine cutoff, and the time step at which the vehicle experiences maximum lateral acceleration. If these other load sets had been run, their line loads could have been plotted against the Max Q line loads in figure 11 to help the structural designer and analyst determine which load sets would be the design drivers causing the highest and most significant structural loads along various sections of the launch vehicle’s structure.

Line Load Versus Vehicle X-Station

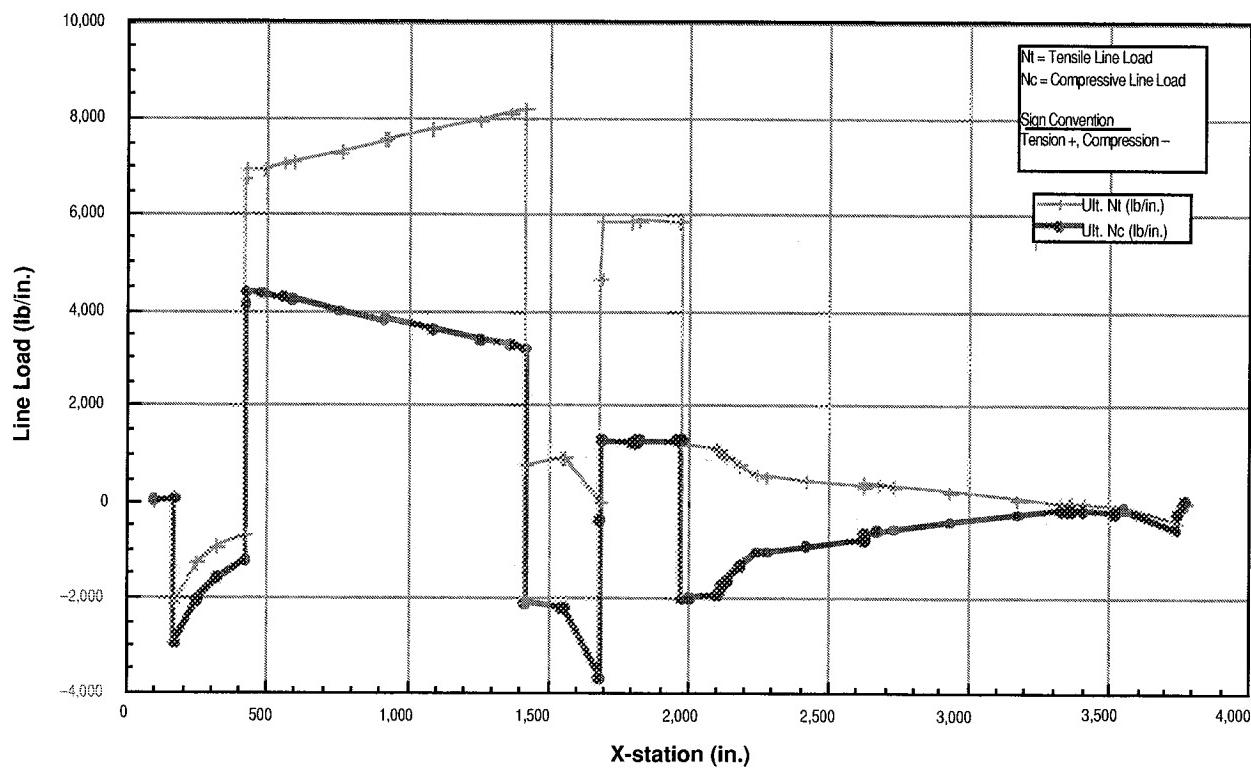


Figure 11. Plot of line loads for the example problem.

7. CONCLUDING REMARKS

The VLOADS program provides the user with an analysis tool for the prediction of structural loads for in-flight launch vehicles, or for other vehicles like upper stages and planetary transfer vehicles. VLOADS may be purchased from COSMIC, University of Georgia, 382 East Broad Street, Athens, GA 30602-4272. COSMIC also has a site on the World Wide Web at <http://www.cosmic.uga.edu/>.

An attractive feature of the VLOADS program is that its Visual Basic source code has been integrated into an easy-to-use Microsoft Excel user interface. The VLOADS program uses the individual Excel worksheets in its Excel workbook as input and output data files in a manner that is very similar to the way that more traditional FORTRAN and BASIC programs have used text files as input and output files in the past. But, because VLOADS has been integrated into an Excel workbook, it is much easier for the user to edit the input data, to run the program, and to view the results than in more traditional FORTRAN and BASIC engineering codes. The use of Excel also allows the user to perform pre- and post-processing calculations directly within the data file.

The major strength of this program is that it enables quick turnaround analysis of structural loads for launch vehicles during the preliminary design phase of the vehicle's developmental lifecycle. This represents a vast improvement over the alternative—the time-consuming and expensive chore of developing finite element models for detailed loads analysis. In preliminary design, much remains unknown about the detailed configuration to which the launch vehicle will mature.

As with other computer tools, the accuracy of the VLOADS analysis is very much dependent upon the accuracy of the input data, as well as the simplifying assumptions built into the program's loads analysis methodology. Solution results, such as interface loads and accelerations, should always be checked for accuracy by hand to ensure that no erroneous data has been entered.

The major shortcoming of this program is its inability to handle a 3- or 6-degree-of-freedom (DOF) analysis. The program can be easily altered to conduct a 3-DOF analysis. This type of analysis would also require a controls study be performed for the vehicle to determine accurate angles of attack, engine gimbal angles, and vehicle rotational velocities. This type of analysis usually requires a much more extensive trajectory analysis than the point mass trajectories run to supply the performance data for the example problem here. If the user desires a 4- or 6-DOF analysis, he/she may break the analysis into pitch plane and yaw plane and combine the two cases by superposition.

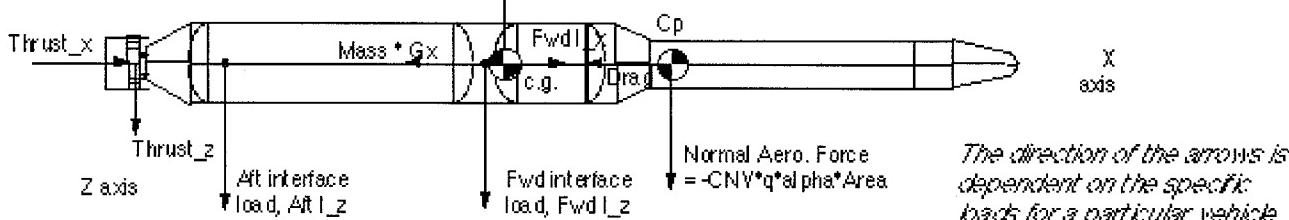
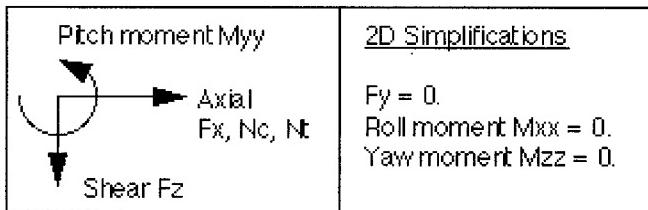
APPENDICES

FREE BODY DIAGRAM AND VLOADS 1.4 INPUT AND OUTPUT FILES

Screen prints of the VLOADS 1.4 input and output screens for the example problem in section 4 are included in these appendices.

VLOADS 1.3.5

If 2 boosters, they are assumed to be attached at $(x, y, z) = (0, \pm y_{booster}, 0)$



ASSUMPTIONS

Acceleration of the total vehicle (G_x, G_z) = Core vehicle acceleration (G_x, G_z).

The booster engine gimbal point (GP) X-station = core engine GP X-station.

Pitch moment $\Sigma M_{yy} = 0$... no rotational acceleration.

<u>TOTAL VEHICLE SYSTEM (Boosters & Core Launch Vehicle)</u>	<u>CORE of LAUNCH VEHICLE ONLY</u>
$\Sigma F_x = \text{Mass_vehicle} * G_x = \text{TotalThrust}_x + \text{Total Drag}$	$\Sigma F_x = \text{Mass_core} * G_x = \text{CoreThrust}_x + \text{CoreDrag} + \text{FwdInterface}_x$
$\Sigma F_z = \text{Mass_vehicle} * G_z = \text{TotalThrust}_z + \text{Total Aero Normal Force}$	$\Sigma F_z = \text{Mass_core} * G_z = \text{CoreThrust}_z + \text{CoreNormal} + \text{AftInterface}_z + \text{FwdInterface}_z$
$\Sigma M_{yy} \text{ about c.g.} = I_{yy} * \text{assumed rotational acceleration of } 0 = 0$ $= (\text{CG_vehicle} - \text{GP}) * \text{TotalThrust}_z + (\text{CG_vehicle} - \text{CP_vehicle}) * \text{Total Normal Force}$	$\Sigma M_{yy} \text{ about c.g.} = I_{yy} * \text{assumed } 0 \text{ rotational acceleration} = 0$ $= (\text{CG_core} - \text{GP}) * \text{CoreThrust}_z + (\text{CG_core} - \text{CP_core}) * \text{CoreNormalForce} + (\text{CG_core} - \text{AA}) * \text{AftIz} + (\text{CG_core} - \text{FA}) * \text{FwdIz}$

NASA MSFC

PD217 Bart Graham and Paul Lue

September 16, 1997

APPENDIX B—Input Data Files for the Example Problem

B.1 “START” Worksheet

VLoads 1.3.5

Launch Vehicle Loads Analysis for Preliminary Design.
by Bart Graham and Paul L. Luz of NASA MSFC / PD21.
Copyright ©1997 National Aeronautics and Space
Administration. No copyright claimed in USA under
Title 17, U.S. Code. All other rights reserved.

EXAMPLE LAUNCH VEHICLE PROBLEM

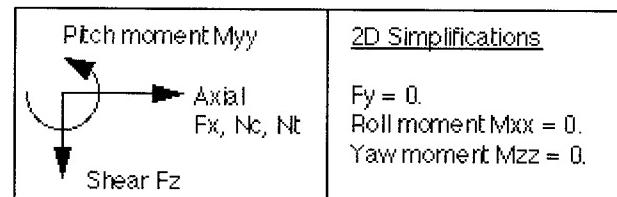
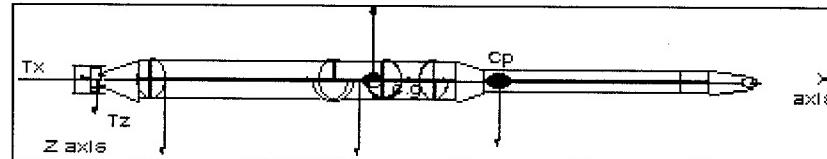
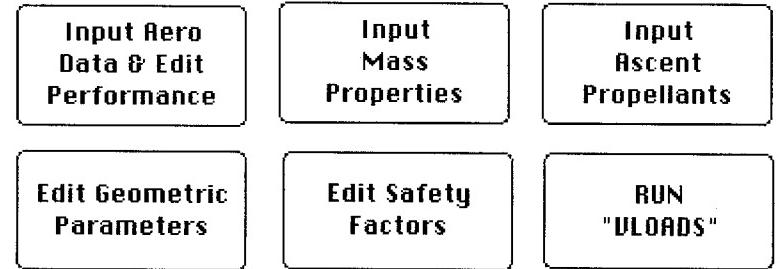
(VLOADS User's Manual, pending publication as NASA Tech. Memorandum)

Load set = **Maximum Dynamic Pressure (Max Q)**

at time = unspecified

Analyst = Bart Graham and Paul Luz

Date = Nov. 1997



OVERVIEW

VLOADS program is a Visual BASIC program that calculates launch vehicle structural loads for preliminary design. Aerodynamic, mass, propellant, propulsion, and performance data are compiled and analyzed to produce distributed shear loads, bending moments, axial forces, and vehicle line loads as a function of X-station. Translational accelerations and interface loads, if any, are also computed.

A VLOADS User's Manual will be published as a NASA Technical Memorandum.

ASSUMPTIONS for Preliminary Design

- * Rigid body.
- * Masses distributed along vehicle centerline at (X,0,0).
- * Loads act in only one plane at a time.
- * Two-dimensional frame of reference.
- * The number of boosters = 0,2,4,6,etc. so that the boosters' drag and axial thrust should react along the core vehicle's centerline, thus negating their contributions to the pitch moment M_{yy} .
- * Rotational acceleration = 0, so that the pitch moment $M_{yy} = 0$.
- * The gimbal point of the boosters, if any, is the same X-station as the core vehicle gimbal point.
- * Engine gimbal angles are small.
- * Angle of attack is small.
- * Vibrational effects are not considered.
- * The Method of Sections is employed to determine loads at a predetermined X-station "node".

B.2 "Aero.DAT"

Launch Vehicle AERODYNAMIC Data as a function of (X/D_ref)

Data may be unsorted. VLOADS will read the raw data, sort it, and then output it to the "Data.SORT" worksheet.

Aerodynamic data in a (X/D_ref) format is convenient because it can still be used if the vehicle's size is photographically scaled.

X / D_ref (unitless)	Cnα per degree	Cd	Comment
10.733	0.03380	0.00000	Normal aero (Table 1)
10.145	0.02410	0.00000	Normal aero (Table 1)
9.596	0.02160	0.00000	Normal aero (Table 1)
8.860	0.01070	0.00000	Normal aero (Table 1)
8.074	0.00440	0.00000	Normal aero (Table 1)
7.309	0.00370	0.00000	Normal aero (Table 1)
6.388	-0.00790	0.00000	Normal aero (Table 1)
5.943	-0.01090	0.00000	Normal aero (Table 1)
5.447	-0.00180	0.00000	Normal aero (Table 1)
4.125	0.00480	0.00000	Normal aero (Table 1)
1.693	0.01740	0.00000	Normal aero (Table 1)
11.322	0.00000	0.09670	Axial aero (Table 2)
11.298	0.00000	0.20250	Axial aero (Table 2)
10.621	0.00000	0.19540	Axial aero (Table 2)
10.152	0.00000	0.03030	Axial aero (Table 2)
6.889	0.00000	0.04310	Axial aero (Table 2)
6.415	0.00000	0.12330	Axial aero (Table 2)

**Go to
START Sheet**

**Edit
Aerodynamic &
Performance
parameters**

VLOADS 1.3.5 (11-5-97)

by Bart Graham and Paul L. Luz.
NASA Marshall Space Flight Center.

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other rights reserved.

VARIABLES

Cnα = Discrete normal force coefficient per
degree alpha (angle-of-attack).
Cd = Discrete drag coefficient.

Project

EXAMPLE LAUNCH VEHICLE PROBLEM

(from VLOADS User's Manual)

Load set = **Maximum Dynamic Pressure (Max Q)**
at time = Unspecified time

Analyst = Bart Graham and Paul Luz
date = March 1996 with VLOADS 1.0, then Nov. 1997 with VLOADS 1.3.5

D_ref = 331 inches

Cn tot = 0.09990
Cd tot = 0.69130

Launch Vehicle MASS Data MINUS Main Propellants

Data may be unsorted. VLOADS will read the raw data, sort it, and then output it to the "Data.SORT" worksheet.

VLOADS assumes that X-stations increase from the bottom of the launch vehicle to the top.

X Station (inches)	Mass (lbm)	Comment
3366.00	3,300	Shroud Nose
2736.00	9,350	Shroud Door +Y
2736.00	9,350	Shroud Door -Y
2628.00	28,000	Strongback
2184.00	10,600	Payload Adapter / ASE
2136.00	17,178	Kickstage (Wet)
2627.00	0	((zero-mass for improved calculations & plots))
2628.00	58,110	Payload +Y
2628.00	58,110	Payload -Y
2629.00	0	((zero-mass for improved calculations & plots))
2112.00	7,090	Transition Structure
2004.00	3,832	Forward ET Structure
1824.00	18,742	LOX Tank & Subsystems
1548.00	16,162	Intertank
912.00	36,452	LH2 Tank & Subsystems
324.00	16,701	Att & Thrust Structure
96.00	20,887	3 SSME engines
252.00	17,207	Prop Subsys & Avionics
1824.00	2,966	Gaseous O2 & Residuals
912.00	1,238	Gaseous H2 & Residuals
252.00	5,557	Att Residuals
166.00	0	((zero-mass for improved calculations & plots))
167.00	0	Approx. engine gimbal plane from drawing.
168.00	0	((zero-mass for improved calculations & plots))
424.00	0	((zero-mass for improved calculations & plots))
425.00	0	Att LH2 Tank Bulkhead
426.00	0	((zero-mass for improved calculations & plots))
485.25	0	
1419.00	0	((zero-mass for improved calculations & plots))
1420.10	0	Forward LH2 Tank Bulkhead
1421.00	0	((zero-mass for improved calculations & plots))
1558.25	0	
1690.00	0	((zero-mass for improved calculations & plots))
1690.45	0	Att LOX Tank Bulkhead
1691.00	0	((zero-mass for improved calculations & plots))
1974.00	0	((zero-mass for improved calculations & plots))
1974.65	0	Forward LOX Tank Bulkhead
1975.00	0	((zero-mass for improved calculations & plots))
2101.65	0	Begin transition from ET-type stage to payload.
2245.65	0	Bottom of Payload Shroud
3325.65	0	Top of Payload Shroud / Base of Nosecone.
3408.81	0	
3774.00	0	
3774.28	0	Tip of Launch Vehicle from drawing.

[Go to
START Sheet](#)

[Edit mass parameters](#)

[Input
Ascent Propellants](#)

VLOADS 1.3.5 (11-5-97)

by Bart Graham and Paul L. Luz.
NASA Marshall Space Flight Center.

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Propellants

Main propellant data should be input on the
Propellant.DAT sheet, if the tanks are inline
and load bearing. All other propellants
should be input on this sheet.

Project

EXAMPLE LAUNCH VEHICLE PROBLEM

(VLOADS User's Manual, pending publication as NASA Tech. Memorandum)

Load set = **Maximum Dynamic Pressure (Max Q)**
at time = unspecified

Analyst = Bart Graham and Paul Luz
date = Nov. 1997

(Mass - Propellants) sum = 340,832.0
Core mass checksum = 1,828,057.0

B.3 "Mass.DAT"

VLoads 1.3.5

Launch Vehicle Loads Analysis for Preliminary Design.
by Bart Graham and Paul L. Luz of NASA/MSFC / PD21.

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EXAMPLE LAUNCH VEHICLE PROBLEM

(VLOADS User's Manual, pending publication as NASA Tech. Memorandum)

Load set = Maximum Dynamic Pressure (Max Q)

at time = unspecified

Analyst = Bart Graham and Paul Luz

Date = Nov. 1997

Main PROPELLANT DATA

[Go to
START Sheet](#)

Optional
AFT
BULKHEAD
(if different than
Mr. FROM
X-station)

Propellant NAME	PRESSURE			MASS			# of X-stations to distribute mass over
	Ullage pressure (psig)	FROM X-station (inches)	TO X-station (inches)	Propellant Mass (lbm)	FROM X-station (inches)	TO X-station (inches)	
Wfp LOX (Max Q)	20.00	1,890.45	1,974.65	1,274,764.00	1,658.25	2,101.05	5
Wfp LH2 (Max Q)	32.00	425.00	1,420.10	212,461.00	425.00	1,420.10	7

The VLOADS program assumes that any propellant tanks input on this sheet are integral and load bearing, meaning that the tank walls are used as the aeroshell skin. Please input all other propellant data, such as reaction control system (RCS) propellants, on the "Mass.DAT" sheet.

For propellants input on this sheet, ullage pressures will be used to relieve the compressive line load vs. X-station. Pressures must be distributed from the aft bulkhead tangency to the forward bulkhead tangency. Do not input pressures for the aft domes and forward domes (because domes are assumed to be non-integral to the vehicle's outer skin).

Main propellant masses will be uniformly distributed for the shear and bending moment distributions, but then will be reassigned to the aft bulkhead tangency points for the axial force distribution.

B.5 “Default.DAT”

6,242,275	167.00	3,183,873	1,335,816
770.4	0.1756	2117.97	0.0766
	807	1,0273	1,558.25
485.25			
			1.4
		717	6
1,876,499	1.3	1.06	331

Total vehicle Thrust	Gimbal Point	Total Vehicle Mass	Mass of Boosters
C.G. of Boosters	Total Vehicle Normal Force Coefficient	Vehicle Center of Pressure	Total Booster Normal Force Coeff.
Total Booster Center of Pressure	Aerodynamic Reference Area	Vehicle Drag Coefficient	Forward Attach Point. Carries X and Z loads only.
Aft Attach Point. Carries Z loads only.	X for Radius Break 1	Radius Break 1	X for Radius Break 2
Radius Break 2	X for Radius Break 3	Radius Break 3	X for Radius Break 4
Radius Break 4	X for Radius Break 5	Radius Break 5	X for Radius Break 6
Radius Break 5	X for Radius Break 7	Radius Break 7	X for Radius Break 8
Radius Break 6	X for Radius Break 9	Radius Break 9	X for Radius Break 10
Radius Break 7	Fuel tank ullage pressure	Oxygen tank ullage pressure	Safety Factor
Fuel tank pressurization	Fuel tank pressure due to	Oxygen tank pressure	Oxygen tank pressure
Zero	zero	function	tubeless
Fuel Tank Mass	Apply Fuel Mass at Fuel Tank Tensioner	Oxygen Mass	Apply Oxygen Mass at Oxygen Tank Tensioner
Mass to zero during axial summation	Mass to zero during axial summation	Mass to zero during axial summation	Mass to zero during axial summation
Mass to zero during axial summation	Mass to zero during axial summation	Dynamic Pressure	Angle of Attack
Thrust of the Core Vehicle	Uncertainty Factor for Bending Moments	Uncertainty Factor for Axial Loads	Aerodynamic Reference Diameter

TT	GP	MV	MD
REF	CNV	CPV	CNE
AREF	CDV	PA	
P1	P1	P2	
P2	P2	P3	
P3	P3	P4	
P4	P4	P5	
P5	P5	P6	
P6	P6	P7	
P7	P7	P8	
P8	P8	P9	
P9	P9	P10	
P10	P10	PQ	
P11	P11	PQ1	
PQ1	PQ1	PQ2	
PQ2	PQ2	DM	
DM	DM	DMX	
DMX	DMX	DP	
DP	DP	DPQ	
DPQ	DPQ	ALPHA	
TC	UFM	UFA	DREF

Geometric Radius breaks
X-station Radii

0.00	128.00
167.00	128.00
426.00	331.20
1,420.10	331.20
1,690.45	331.20
1,974.65	331.20
2,101.65	331.20
2,246.65	432.00
3,325.65	432.00
3,774.28	20.00

lbs.	inches	lbm	lbm
inches	—	inches	—
inches	sq. ft.	—	inches
inches	inches	inches	inches
inches	inches	inches	inches
inches	inches	inches	inches
inches	inches	inches	inches
inches	inches	inches	inches
inches	psig	psig	—
inches	inches	inches	inches
lbm	inches	lbm	inches
lbm	lbm	lbm	lbm
lbm	lbm	psf	degrees
lbs.	—	—	inches

APPENDIX C—Output Data Files for the Example Problem

C.1 “Data.SORT”

VLoads 1.3.5

by Bart Graham and Paul L. Luz of NASA MSFC / PD21.
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 Administration. No copyright claimed in USA under
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Aero elements = 17
 Dry mass elements = 44
 Fluid mass elements = 12

EXAMPLE LAUNCH VEHICLE PROBLEM

(VLOADS User's Manual, pending publication as NASA Tech. Memorandum)

Project = **EXAMPLE LAUNCH VEHICLE PROBLEM**
 Load set = **Maximum Dynamic Pressure (Max Q)**
 at time = **unspecified**
 Analyst = **Bart Graham and Paul Luz**
 Date = **Nov. 1997**

SORTED DATA: Aerodynamics, Mass Properties, and Ascent Propellants

X sta (inches)	Cna	Cd	Mass (lbm)	Pressure (psig)	Comments
96.00	0.00000	0.00000	20,887.00		3 SSME engines
166.00	0.00000	0.00000	0.00		((zero-mass for improved calculations & plots)
167.00	0.00000	0.00000	0.00		Approx. engine gimbal plane from drawing.
168.00	0.00000	0.00000	0.00		((zero-mass for improved calculations & plots)
252.00	0.00000	0.00000	17,207.00		Prop Subsys & Avionics
252.00	0.00000	0.00000	5,557.00		Aft Residuals
324.00	0.00000	0.00000	16,701.00		Aft & Thrust Structure
424.00	0.00000	0.00000	0.00		((zero-mass for improved calculations & plots)
425.00	0.00000	0.00000	32.00		Wp LH2 (Max Q) pressure/ Aft LH2 Tank Bulkhead
425.00	0.00000	0.00000	30,351.57		Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
426.00	0.00000	0.00000	0.00		Wp LH2 (Max Q) pressure/ ((zero-mass for improved calculations & plots)
485.25	0.00000	0.00000	0.00		Wp LH2 (Max Q) pressure/
560.25	0.01740	0.00000	0.00		Wp LH2 (Max Q) pressure/ Normal aero (Table 1)
590.85	0.00000	0.00000	30,351.57		Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
756.70	0.00000	0.00000	30,351.57		Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
912.00	0.00000	0.00000	36,452.00		Wp LH2 (Max Q) pressure/ LH2 Tank & Subsystems
912.00	0.00000	0.00000	1,238.00		Wp LH2 (Max Q) pressure/ Gaseous H2 & Residuals
922.55	0.00000	0.00000	30,351.57		Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
1,088.40	0.00000	0.00000	30,351.57		Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
1,254.25	0.00000	0.00000	30,351.57		Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
1,365.31	0.00480	0.00000	0.00		Wp LH2 (Max Q) pressure/ Normal aero (Table 1)
1,419.00	0.00000	0.00000	0.00		Wp LH2 (Max Q) pressure/ ((zero-mass for improved calculations & plots)
1,420.10	0.00000	0.00000	0.00		Wp LH2 (Max Q) pressure/ Forward LH2 Tank Bulkhead
1,420.10	0.00000	0.00000	30,351.57		Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
1,421.00	0.00000	0.00000	0.00		((zero-mass for improved calculations & plots)
1,548.00	0.00000	0.00000	16,162.00		Intertank
1,558.25	0.00000	0.00000	0.00		
1,558.25	0.00000	0.00000	254,952.80		Wp LOX (Max Q) mass
1,690.00	0.00000	0.00000	0.00		((zero-mass for improved calculations & plots)
1,690.45	0.00000	0.00000	0.00		Wp LOX (Max Q) pressure/ Aft LOX Tank Bulkhead
1,691.00	0.00000	0.00000	0.00		Wp LOX (Max Q) pressure/ ((zero-mass for improved calculations & plots)
1,694.10	0.00000	0.00000	254,952.80		Wp LOX (Max Q) pressure/ Wp LOX (Max Q) mass
1,802.86	-0.00180	0.00000	0.00		Wp LOX (Max Q) pressure/ Normal aero (Table 1)
1,824.00	0.00000	0.00000	18,742.00		Wp LOX (Max Q) pressure/ LOX Tank & Subsystems
1,824.00	0.00000	0.00000	2,966.00		Wp LOX (Max Q) pressure/ Gaseous O2 & Residuals
1,829.95	0.00000	0.00000	254,952.80		Wp LOX (Max Q) pressure/ Wp LOX (Max Q) mass
1,965.80	0.00000	0.00000	254,952.80		Wp LOX (Max Q) pressure/ Wp LOX (Max Q) mass
1,967.10	-0.01090	0.00000	0.00		Wp LOX (Max Q) pressure/ Normal aero (Table 1)
1,974.00	0.00000	0.00000	0.00		Wp LOX (Max Q) pressure/ ((zero-mass for improved calculations & plots)
1,974.65	0.00000	0.00000	0.00		Wp LOX (Max Q) pressure/ Forward LOX Tank Bulkhead
1,975.00	0.00000	0.00000	0.00		((zero-mass for improved calculations & plots)
2,004.00	0.00000	0.00000	3,832.00		Forward ET Structure
2,101.65	0.00000	0.00000	0.00		Begin transition from ET-type stage to payload.

C.1 “Data.SORT” (Continued)

2,101.65	0.00000	0.00000	254,952.80	Wp LOX (Max Q) mass
2,112.00	0.00000	0.00000	7,090.00	Transition Structure
2,114.26	-0.00790	0.00000	0.00	Normal aero (Table 1)
2,123.27	0.00000	0.12330	0.00	Axial aero (Table 2)
2,136.00	0.00000	0.00000	17,178.00	Kickstage (Wet)
2,184.00	0.00000	0.00000	10,600.00	Payload Adapter / ASE
2,245.65	0.00000	0.00000	0.00	Bottom of Payload Shroud
2,280.39	0.00000	0.04310	0.00	Axial aero (Table 2)
2,419.41	0.00370	0.00000	0.00	Normal aero (Table 1)
2,627.00	0.00000	0.00000	0.00	((zero-mass for improved calculations & plots)
2,628.00	0.00000	0.00000	28,000.00	Strongback
2,628.00	0.00000	0.00000	58,110.00	Payload +Y
2,628.00	0.00000	0.00000	58,110.00	Payload -Y
2,629.00	0.00000	0.00000	0.00	((zero-mass for improved calculations & plots)
2,672.46	0.00440	0.00000	0.00	Normal aero (Table 1)
2,736.00	0.00000	0.00000	9,350.00	Shroud Door +Y
2,736.00	0.00000	0.00000	9,350.00	Shroud Door -Y
2,932.79	0.01070	0.00000	0.00	Normal aero (Table 1)
3,176.14	0.02160	0.00000	0.00	Normal aero (Table 1)
3,325.65	0.00000	0.00000	0.00	Top of Payload Shroud / Base of Nosecone.
3,357.96	0.02410	0.00000	0.00	Normal aero (Table 1)
3,360.41	0.00000	0.03030	0.00	Axial aero (Table 2)
3,366.00	0.00000	0.00000	3,300.00	Shroud Nose
3,408.81	0.00000	0.00000	0.00	Axial aero (Table 2)
3,515.62	0.00000	0.19540	0.00	Normal aero (Table 1)
3,552.52	0.03380	0.00000	0.00	Axial aero (Table 2)
3,739.54	0.00000	0.20250	0.00	Axial aero (Table 2)
3,747.58	0.00000	0.09670	0.00	Axial aero (Table 2)
3,774.00	0.00000	0.00000	0.00	Tip of Launch Vehicle from drawing.
SUM	core Cna	core Cd	Mass	Total Core Vehicle Mass = 1,828,057
	0	1	1,828,057.00	Core vehicle CG = 1,731.17
TOTAL	Aero. Norm. force -260,870	Aero. Drag force -300,867	lbs.	Core vehicle CP = 2,969.08 Total vehicle CP = 2,117.97 Vehicle Normal Force Coeff = 0.17560 (core + boosters) Vehicle Drag Force Coeff = 1.02730 (core + boosters) CoreNormalAeroForce = -260,870.27 Multiple Boosters (2,4,6,8,etc.) are attached to the launch vehicle. Alt Interface Iz = -161,878.5 Fwd Interface Iz = 60,817.4 Fwd Interface Ix = 1,970,329.1 THRUST OF THE CORE Axial Thrust (assumed = input ThrustCore) = 1,674,381.0 Lateral Thrust, TzCore = -84,238.1 Engine gimbal angle (for 0 pitch moment) = -2.88 degrees. Magnitude of the engines' thrust = 1,676,498.7 Sum of the Moments = 0.0000 Sum of Forces in Z (lateral) = 0.0000 Sum of Forces in X (axial) = 0.0000 Axial acceleration = 1.8292 g's (Earth). Lateral acceleration = -0.2441 g's (Earth).

C.2 “Loads.OUT”

VLoads 1.3.5

Launch Vehicle Loads Analysis for Preliminary Design.
by Bart Graham and Paul L. Luz of NASA MSFC / PD21.

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Axial acceleration = 1.8292 g's (Earth).
Lateral acceleration = -0.2441 g's (Earth).

Multiple Boosters (2,4,6,8,etc.) attached to the vehicle.
X= 486.25 - Aft Interface Iz = -161,878.5 lbs.
X= 1,558.25 - Fwd Interface Iz = 80,817.4 lbs.
X= 1,558.25 - Fwd Interface Ix = 1,970,329.1 lbs.

Project = EXAMPLE LAUNCH VEHICLE PROBLEM

(VLOADS User's Manual, pending publication as NASA Tech. Memorandum)

Load set = Maximum Dynamic Pressure (Max Q)

at time = unspecified

Analyst = Bart Graham and Paul Luz

Date = Nov. 1997

These factors were only used for the Nc & Nt line loads.

Uncertainty factor for bending moments = 1.3

Uncertainty factor for axial loads = 1.05

Safety Factor (SF) = 1.4

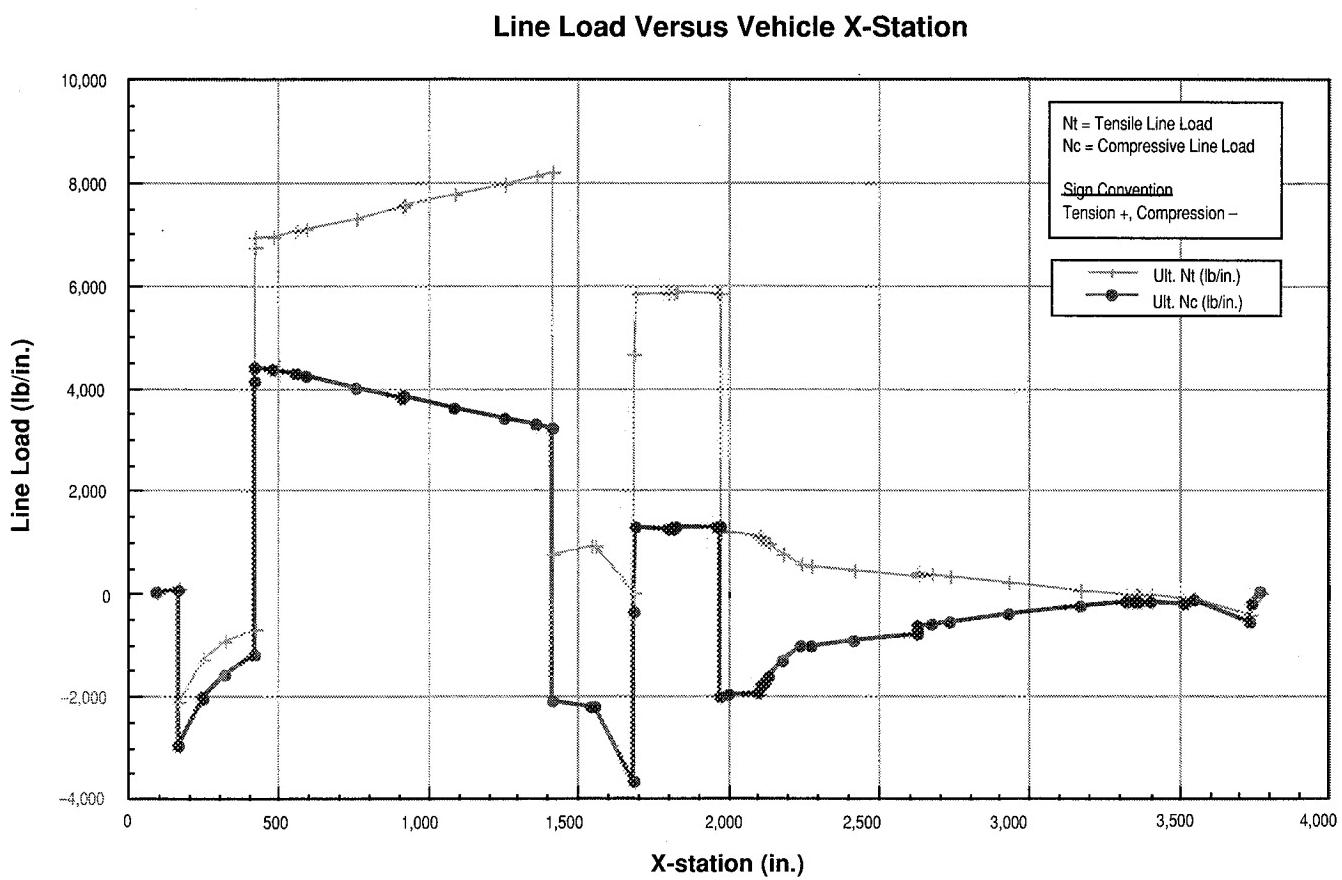
SF was NOT applied to “Relief” loads.

X Station (inches)	Limit SHEAR (lbf)	Limit MOMENT (in-lbs)	Limit AXIAL (lbf)	Limit Pressure (psig)	RADIUS (inches)	Ult. Nc (lbs/inch)	Ult. Nt (lbs/inch)	COMMENTS
96.00	0	0	0		128.00	0.00	0.00	3 SSME engines
166.00	5,098	356,849	38,206		128.00	37.26	82.46	((zero-mass for improved calculations & plots)
187.00	5,098	361,947	38,206		128.00	37.08	82.63	Approx. engine gimbal plane from drawing.
168.00	- 79,140	282,806	- 1,636,175		128.79	- 2,982.18	- 2,113.20	((zero-mass for improved calculations & plots)
252.00	- 79,140	- 6,364,972	- 1,636,175		194.95	- 2,060.63	- 1,305.55	Prop. Subsys & Avionics
252.00	- 74,941	- 6,364,972	- 1,604,700		194.95	- 2,022.86	- 1,278.57	Aft Residuals
324.00	- 73,584	- 11,663,039	- 1,594,536		251.65	- 1,589.11	- 952.18	Aft & Thrust Structure
424.00	- 69,508	- 18,613,849	- 1,563,986		330.41	- 1,206.20	- 692.24	((zero-mass for improved calculations & plots)
425.00	- 69,508	- 18,683,357	- 1,563,986	32.00	331.20	4,095.74	6,728.42	Wp LH2 (Max Q) pressure/ Aft LH2 Tank Bulkhead
425.00	- 69,508	- 18,683,357	- 1,563,986	32.00	331.20	4,095.74	6,728.42	Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
426.00	- 62,100	- 18,745,457	- 1,175,357	32.00	331.20	4,369.93	6,924.83	Wp LH2 (Max Q) pressure/ ((zero-mass for improved calculations
485.25	- 62,100	- 22,424,898	- 1,175,357	32.00	331.20	4,350.50	6,944.27	Wp LH2 (Max Q) pressure/
560.25	- 223,979	- 39,223,438	- 1,175,357	32.00	331.20	4,261.78	7,032.98	Wp LH2 (Max Q) pressure/ Normal aero (Table 1)
590.85	- 269,416	- 47,467,394	- 1,175,357	32.00	331.20	4,218.24	7,076.52	Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
756.70	- 262,008	- 90,921,384	- 1,175,357	32.00	331.20	3,988.75	7,306.02	Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
912.00	- 254,600	- 130,460,755	- 1,175,357	32.00	331.20	3,779.93	7,514.84	Wp LH2 (Max Q) pressure/ LH2 Tank & Subsystems
912.00	- 245,703	- 130,460,755	- 1,108,660	32.00	331.20	3,827.03	7,548.48	Wp LH2 (Max Q) pressure/ Gaseous H2 & Residuals
922.55	- 245,401	- 133,049,736	- 1,108,415	32.00	331.20	3,814.96	7,583.29	Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
1088.40	- 237,993	- 172,520,909	- 1,108,415	32.00	331.20	3,606.50	7,771.75	Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
1254.25	- 230,585	- 210,763,493	- 1,108,415	32.00	331.20	3,404.53	7,973.72	Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
1366.31	- 223,178	- 235,549,322	- 1,108,415	32.00	331.20	3,273.53	8,104.83	Wp LH2 (Max Q) pressure/ Normal aero (Table 1)
1419.00	- 235,712	- 248,204,974	- 1,108,415	32.00	331.20	3,206.79	8,171.46	Wp LH2 (Max Q) pressure/ ((zero-mass for improved calculations
1420.10	- 235,712	- 248,464,257	- 1,108,415	32.00	331.20	3,206.42	8,172.83	Wp LH2 (Max Q) pressure/ Forward LH2 Tank Bulkhead
1420.10	- 235,712	- 248,464,257	- 1,108,415	32.00	331.20	3,206.42	8,172.83	Wp LH2 (Max Q) pressure/ Wp LH2 (Max Q) mass
1421.00	- 228,304	- 248,669,730	- 1,108,415		331.20	- 2,094.87	756.04	((zero-mass for improved calculations & plots)
1548.00	- 228,304	- 277,664,340	- 1,108,415		331.20	- 2,247.99	908.17	Intertank
1558.25	- 224,359	- 279,964,023	- 1,076,852		331.20	- 2,239.26	936.23	
1558.25	- 224,359	- 279,964,023	- 1,076,852		331.20	- 2,239.26	936.23	Wp LOX (Max Q) mass

C.2 “Loads.OUT” (Continued)

1690.00	- 101,316	- 293,312,440	- 3,047,181		331.20	- 3,701.58	11.56	((zero-mass for improved calculations & plots)
1690.45	- 101,316	- 293,358,033	- 3,047,181	20.00	331.20	- 389.82	4,648.80	Wp LOX (Max Q) pressure/ Aft LOX Tank Bulkhead
1691.00	- 101,316	- 293,413,757	- 715,410	20.00	331.20	1,257.03	5,825.43	Wp LOX (Max Q) pressure/ ((zero-mass for improved calculation
1694.10	- 101,316	- 293,727,837	- 715,410	20.00	331.20	1,255.37	5,827.09	Wp LOX (Max Q) pressure/ Wp LOX (Max Q) mass
1802.86	- 39,091	- 297,979,236	- 715,410	20.00	331.20	1,232.92	5,849.55	Wp LOX (Max Q) pressure/ Normal aero (Table 1)
1824.00	- 34,390	- 298,706,324	- 715,410	20.00	331.20	1,229.08	5,863.39	Wp LOX (Max Q) pressure/ LOX Tank & Subsystems
1824.00	- 29,816	- 298,706,324	- 681,128	20.00	331.20	1,253.30	5,870.68	Wp LOX (Max Q) pressure/ Gaseous O2 & Residuals
1829.95	- 29,092	- 298,879,421	- 675,702	20.00	331.20	1,266.22	5,874.33	Wp LOX (Max Q) pressure/ Wp LOX (Max Q) mass
1965.80	33,134	- 294,378,203	- 675,702	20.00	331.20	1,279.99	5,850.56	Wp LOX (Max Q) pressure/ Wp LOX (Max Q) mass
1987.10	95,359	- 294,254,245	- 675,702	20.00	331.20	1,280.64	5,849.91	Wp LOX (Max Q) pressure/ Normal aero (Table 1)
1974.00	123,823	- 293,399,856	- 675,702	20.00	331.20	1,285.16	5,846.40	Wp LOX (Max Q) pressure/ ((zero-mass for improved calculation
1974.65	123,823	- 293,319,371	- 675,702	20.00	331.20	1,285.58	5,844.97	Wp LOX (Max Q) pressure/ Forward LOX Tank Bulkhead
1975.00	123,823	- 293,276,033	- 675,702		331.20	- 2,026.19	1,207.94	((zero-mass for improved calculations & plots)
2004.00	123,823	- 289,885,173	- 675,702		331.20	- 2,007.23	1,188.98	Forward ET Structure
2101.65	124,758	- 277,502,552	- 668,693		331.20	- 1,937.94	1,128.17	Begin transition from ET-type stage to payload.
2101.65	124,758	- 277,502,552	- 668,693		331.20	- 1,937.94	1,128.17	Wp LOX (Max Q) mass
2112.00	186,984	- 275,567,270	- 668,693		338.45	- 1,855.96	1,063.53	Transition Structure
2114.26	188,714	- 275,140,304	- 655,724		340.03	- 1,829.79	1,056.35	Normal aero (Table 1)
2123.27	209,344	- 273,255,542	- 655,724		346.33	- 1,762.76	1,003.40	Axial aero (Table 2)
2136.00	209,344	- 270,589,899	- 602,061		355.25	- 1,638.66	958.94	Kickstage (Wet)
2184.00	213,536	- 260,339,964	- 570,640		388.85	- 1,340.83	762.25	Payload Adapter / ASE
2245.65	216,123	- 247,015,965	- 551,250		432.00	- 1,065.33	563.55	Bottom of Payload Shroud
2280.38	216,123	- 239,507,541	- 551,250		432.00	- 1,042.03	530.24	Axial aero (Table 2)
2419.41	216,123	- 209,462,085	- 532,493		432.00	- 938.60	444.23	Normal aero (Table 1)
2627.00	206,461	- 166,603,053	- 532,493		432.00	- 805.56	311.19	((zero-mass for improved calculations & plots)
2628.00	206,461	- 166,396,591	- 532,493		432.00	- 804.91	310.55	Strongback
2628.00	213,295	- 166,396,591	- 481,276		432.00	- 777.18	330.36	Payload +Y
2628.00	227,478	- 166,396,591	- 374,982		432.00	- 719.61	371.48	Payload -Y
2629.00	241,661	- 166,154,930	- 268,688		432.00	- 661.30	411.85	((zero-mass for improved calculations & plots)
2672.46	241,661	- 155,652,134	- 268,688		432.00	- 628.69	379.24	Normal aero (Table 1)
2736.00	230,171	- 141,027,273	- 268,688		432.00	- 583.29	333.84	Shroud Door +Y
2736.00	232,453	- 141,027,273	- 251,588		432.00	- 574.03	340.46	Shroud Door -Y
2932.79	234,735	- 94,833,190	- 234,483		432.00	- 421.37	203.88	Normal aero (Table 1)
3176.14	206,784	- 44,509,612	- 234,483		432.00	- 286.16	47.46	Normal aero (Table 1)
3325.65	150,390	- 22,025,395	- 234,483		432.00	- 195.36	- 22.33	Top of Payload Shroud / Base of Nosecone.
3357.96	150,390	- 17,166,020	- 234,483		402.33	- 197.79	- 36.96	Normal aero (Table 1)
3360.41	87,457	- 16,951,803	- 234,483		400.08	- 198.48	- 36.56	Axial aero (Table 2)
3366.00	87,457	- 16,463,032	- 221,296		394.94	- 192.24	- 32.49	Shroud Nose
3408.81	88,262	- 12,684,518	- 215,259		365.63	- 199.72	- 43.05	
3615.62	88,262	- 3,257,457	- 215,259		267.54	- 224.00	- 111.22	Axial aero (Table 2)
3552.52	88,262	0	- 130,218		223.65	- 136.22	- 97.30	Normal aero (Table 1)
3739.54	0	0	- 130,218		51.90	- 586.95	- 419.25	Axial aero (Table 2)
3747.58	0	0	- 42,086		44.52	- 221.17	- 157.98	Axial aero (Table 2)
3774.00	0	0	0		20.26	- 0.00	0.00	
3774.28	0	0	0		20.00	- 0.00	0.00	Tip of Launch Vehicle from drawing.
MIN	- 269,416	- 298,879,424	- 3,047,181			- 3,701.58	- 2,113.20	MIN
MAX	241,661	361,947	38,206			4,369.93	8,172.83	MAX

C.3 “Loads.PLOT”



APPROVAL

PRELIMINARY IN-FLIGHT LOADS ANALYSIS OF IN-LINE LAUNCH VEHICLES USING THE VLOADS 1.4 PROGRAM

J.B.Graham and P.L. Luz

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.



A. ROTH
DIRECTOR, PROGRAM DEVELOPMENT DIRECTORATE

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<p>To calculate structural loads of in-line launch vehicles for preliminary design, a very useful computer program is VLOADS 1.4. This software may also be used to calculate structural loads for upper stages and planetary transfer vehicles. Launch vehicle inputs such as aerodynamic coefficients, mass properties, propellants, engine thrusts, and performance data are compiled and analyzed by VLOADS to produce distributed shear loads, bending moments, axial forces, and vehicle line loads as a function of X-station along the vehicle's length. Interface loads, if any, and translational accelerations are also computed. The major strength of the software is that it enables quick turnaround analysis of structural loads for launch vehicles during the preliminary design stage of its development. This represents a significant improvement over the alternative—the time-consuming and expensive chore of developing finite element models. VLOADS was developed as a Visual BASIC macro in a Microsoft Excel 5.0 workbook on a Macintosh. VLOADS has also been implemented on a PC computer using Microsoft Excel 7.0a for Windows 95. VLOADS was developed in 1996, and the current version was released to COSMIC, NASA's Software Technology Transfer Center, in 1997. The program is a copyrighted work with all copyright vested in NASA.</p>			
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